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FOREST SERVICE

PROGRAM DIRECTION FOR

FOREST PRODUCTS UTILIZATION RESEARCH

IN THE FOREST SERVICE

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PROGRAM DIRECTION FOR FOREST PRODUCTS UTILIZATION RESEARCH IN THE FOREST SERVICE

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January 30, 1984

THIS REPORT IS DEDICATED TO THE FOND MEMORY OF

DR. GEORGE G. MARRA, A PIONEERING WOOD SCIENTIST

AND A VERY UNDERSTANDING HUMAN BEING.

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EXECUTIVE SUMMARY

The purpose of this report is to provide Forest Service research managers with a description of the structure and content of programs in utilization research and a proposed framework for concentrating future research efforts.

Forest products utilization research is a major component of the total Forest Service research effort (14.5 percent of the total budget). The purpose of this research is to provide more options for utilizing all forms and qualities of wood to improve timber management, to extend timber supplies, and to develop the scientific base of knowledge needed to provide safe and durable wood materials for the public. The Forest Service has stewardship of over 190 million acres of National Forest land. As such, it has responsibility for maximum timber productivity, in addition to other uses of the forest, and productivity is strongly related to progress in utilization practices.

Forest products utilization research is being conducted by private industry and universities, in addition to the Forest Service. Research by universities and the Forest Service generally is long term and high risk, favoring the basic or fundamental spectrum of research. Industry generally conducts short-term, problem-solving research aimed at product or process improvements, and competitive market positions.

About 70 percent of the Forest Service utilization research effort resides at the Forest Products Laboratory. The remaining efforts are located at ten laboratories in the Intermountain, North Central, Northeast, Pacific Northwest, Rocky Mountain, South, and Southeast. In general, the Forest Products Laboratory has a national mission, whereas the field locations have missions linked to their geographical regions. In practice, all research results, regardless of source, may be used regionally, nationally, or internationally. Coordination is provided by the Deputy Chief for Research located in Washington, D.C.

Forest products utilization research in the Forest Service has a long productive history. Current basic knowledge on the characteristics and properties of wood, the engineering basis for structures, and a wide variety of wood products, came largely from Forest Service research. Forest Service research has also made significant contributions in the field of paper science and technology. Continuing research efforts and spinoffs from accelerated efforts during the World Wars provide the basis for sawing, milling, lumber drying, gluing, and panel products--a major segment of the wood products industry. New and improved pulping processes were invented. Research on reliable design criteria for wood structures and improved protection of wood in use have extended national timber supplies. Basic and applied research on wood performance in different applications has made possible the utilization of up to 95 percent of the wood brought to mills. At the turn of the century, only 35 percent of the wood was utilized.

Current research efforts continue this list of accomplishments. A new press-dry papermaking process demonstrates that underutilized hardwoods can replace softwoods in liner-board for containers--a major consumer of wood. Commercial application of the process could be the most significant advancement in pulp and paper in the past 30 to 50 years. A new Forest Service construction technique, the Truss-Framed System, is now being adopted. This labor, cost, and materials saving method of construction will

make homes affordable to a much greater proportion of Americans at a time when housing starts are at an all time low. Advances in basic microbial research promises energy saving techniques for wood pulping and for clarifying pulpmill effluents. New structural panels have been developed and adopted commercially.

A look to the future indicates that utilization research should concentrate on ways to utilize small trees, alternative species, forest residues, and waste paper. Although, the level of utilization within most primary and secondary wood processing plants is approaching 100 percent, there are exceptions to this trend in many small sawmills and wood finishing plants. Great strides have also been made in utilizing forest residues and other underutilized materials, but there is still a great opportunity to take advantage of these huge tonnages that are still being wasted. From a research standpoint, there is a continuing need to emphasize effective use of wood, in addition to increased recovery on a percentage basis.

The following items summarize the main points in this report:

1. Current programs of the Forest Service have 130 scientists conducting utilization research. Ninety-one are at the Forest Products Laboratory and the remainder are located at Forest and Range Experiment Stations. Following is a listing of program areas and number of scientists.

Program area	Scientist years
Processing of lumber and wood products	30
Adhesives	7 1/2
Chemicals and energy from wood	10
Pulp, paper, and packaging	18
Construction materials properties and fire safety	26 1/2
Protection of wood	12
Biodegradation	3
Wood anatomy and tropical wood utilization	4
In-woods processing for improved utilization	4
Biomass characterization and measurement for forest product recovery	15
Total	130

2. Financial support for forest products utilization research has compared favorably with the total Forest Service research budget over the 5-year period between 1977 through 1981. Adjusted to 1977, the 1981 budget for utilization research was 9 percent over the 1977 appropriation, while the Forest Service research budget for 1981 was increased by about 1 percent. Fiscal year 1982 showed a slight drop in budget for utilization research followed by another drop in 1983 and 1984. The future projected outlook for FY 1985 indicates about the same level of funding (1984 level) in all research programs. This necessitates more careful planning and to place stricter priorities on all programs.

3. Accomplishments and benefits from Forest Service research in forest products extending over 80 years has been significant. The benefits range from new jobs for an expanding population, to better homes and safer structures for everyone. Even more significant is the confidence engendered in the Nation's forests as a dependable, renewable source of valuable raw materials capable of contributing to economic growth indefinetely.

Considered as an investment, the returns from expenditures in forest products research are impressive. Total Federal expenditures in this field of research since 1900 are about $200 million while the economic impacts from new processes and products resulting from the new information can easily be reckoned in billions of dollars. In addition to making a substantial contribution to national welfare, the impact on GNP over the years has returned the investment many times over in new taxes to the Federal Treasury.

4. Planning will require close attention to professional staffing. At present, nearly 40 percent of the scientists in utilization research are in the Forest Products Technologist series. Twenty percent are in the Chemical Engineering and Chemist series, and 20 percent are in the Engineering series. The remaining 20 percent are spread among nine Professional series. Thirty-five percent of the scientists in utilization research hold Ph.D.'s compared to the Forest Service research total of 44 percent. About one-third of the scientists are over 50 years old. Therefore, we can expect a number of position openings in the next 5 to 10 years. Strong efforts should be made to recruit Ph.D. scientists and young, promising professionals with skills to coincide with future program directions.

5. Coordination of utilization research programs in the Forest Service becomes increasingly important as the competition for a diminishing budget increases. Coordination must include: internal programs; research conducted by other federal agencies; university programs; research in other countries; and research needed or underway in the private sector.

6. The productivity of utilization research scientists and projects compare favorably with the total Forest Service research program. Using only publications as a measure, utilization research produced two publications per scientist-year between 1977 and 1981. This is close to the total Forest Service research average. The range per utilization research scientist was from 0.2 to 10.4 publications per scientist per year. Recognizing that publications are only one measure of productivity, research managers should review carefully the total outputs of each scientist. Scientists with only one or two publications in 5 years, or those with no sole or senior authorship papers, should receive careful attention.

7. Looking to the future, current administration policy states that federal research expenditures shall be for high-risk, long-term research which the private sector is unlikely to fund. The research must also be directed to support technology development needed to achieve national objectives.

The prospects of declining budgets may require de-emphasizing some important current research in favor of higher priority programs. Assuring the continuing supply of wood-based commodities through good forest management is

a national responsibility of the Forest Service. The problems surrounding the economic use of forest-based residues and underutilized species are delaying the full productive capability of our nation's forests. These underutilized resources can help meet the expanding demand, both nationally and internationally, for forest-based products.

Concurrently, all managers from the project level up must aggressively search for ways to include user groups in the R&D process, and develop opportunities for shared funding. Finer lines may have to be drawn on the responsibilities for developmental work. User groups must share in or totally support the prototype or implementing phases of some types of research. These particular phases occur when scale-up is required from bench experiments to proof-of-concept experiments. Subsequent phases, i.e., proof-of-feasibility, may require major support by user groups.

8. A framework for planning future utilization research programs should include the following "areas-of-concentration."

(a) Concentrate research on structural composite products to studies which lead to better understanding of basic mechanisms and principles of raw material qualities, mechanics and chemistry of formation--including adhesives and adhesion--, engineering properties and design criteria, and durability against adverse environments and fire hazards.

(b) Concentrate research in papermaking to reactions and processes which efficiently convert hardwood and recycled fiber to paper with adequate performance properties, and on facets of papermaking that lead to engineering properties and engineered uses.

(c) Concentrate research on the chemistry and microbial technology of wood to reactions and processes that improve the yield and quality of pulp and chemicals, and reduce energy and pollution loads.

(d) Concentrate research on basic engineering properties of wood to factors that affect properties such as defects, changing growth rate, duration of load, chemical treatments, and environmental influences.

(e) Concentrate research on design criteria to fastener performance, and computerized three-dimensional design models for complete structures to provide efficient structures, including those using composite materials and unitized components.

(f) Concentrate research on wood protection to reactions and processes leading to safe new wood preservation methods, including chemical modification of wood.

(g) Concentrate research on western species to the characterization and product potential of dead and dying trees, logging residues, and hardwoods.

(h) Concentrate research on eastern species to the potentials for total utilization, including all types of ownership and site classification.

For planning purposes, it is important that research managers agree on "areas-of-concentration" for utilization research. Within each "area-of-concentration," the scientists of Research Work Units and the research managers should develop specific goals and concentrate the available

resources more narrowly than in the past. Stronger coordination between Stations, the Forest Products Laboratory, and the Washington Office Research Staff will be required to define and select the problem areas and allocate resources.

9. Goals should be set within the "areas-of-concentration." A listing of possible high-risk, high-payoff goals is included as examples for discussion purposes as new program directions are developed for Stations, Forest Products Laboratory, and Research Work Units. These are consistent with the priorities established by RPA Research Thrusts, the NFPA/CORE and API/TAPPI Committees, and by NASULGC.

a. Principles for the composition and internal structure of reconstituted wood products from mixed species and residues to achieve high performance

b. New nonpetroleum-based adhesives for reconstituted wood products

c. A new energy-efficient, nonpolluting pulping process

d. Strong paper for engineered structural applications

e. Chemical and microbial processes to efficiently convert wood for improved yields of chemicals and pulp

f. Computer programs for studying and improving the reliability of wood structures, including those using composite wood products, and those using modular and component systems

g. Fundamental data base on the properties of wood under varying environmental conditions, and chemical treatments

h. Processes for chemically modifying wood to extend its life and performance in use

i. Economical options to utilize at least a third of the logging residues and other unused trees left after logging in the West

j. Economical processes to utilize the excess of small, rough, and cull mixed hardwood trees in the East

These examples illustrate that the potential for significant accomplishments and benefits from research are just as great now as they were 80 years ago. This results from the fact that advances in other fields of science and technology interact with our own advances. The net effect is continually to expose new problems and to provide new opportunities to deal effectively with problems previously considered unsolvable or uneconomic.

10. Guidelines for Leadership. The Forest Service has long been a world leader in all important areas of wood research. But, the time is approaching when this will no longer be possible. It will be necessary to select for world leadership those areas of research that will achieve the highest returns consistent with the overall Forest Service mission. In general, the areas will be characterized as being of special importance in which the Forest

Service is uniquely capable of making a significant contribution. This will require continuous appraisals of the resources available to best accomplish these goals. The major considerations will include wise deployment of scientists and technologists, and enhanced management skills to extract high levels of intellectual output from each individual.

PREFACE

The purpose of this report is to provide information to assist in establishing directions for future programs in forest products utilization research (FPUR). It discusses the historical development of Forest Service research in forest products utilization, coordination of research, current organizational structure and programs, performance and major accomplishments, funding, and a framework for future emphasis.

Harvesting and economics research are recognized as areas of great importance to all utilization programs. It is crucial that both be closely integrated with utilization research, but this report, in the interest of brevity, focuses on the single line item, forest products utilization research. Further discussions should be planned soon to develop means by which a closer integration of harvesting, economics, and utilization can be achieved.

One of the most notable achievements of utilization research has been to substantially minimize the threat of a timber famine, a turn-of-the-century fear. This was accomplished through the development of more efficient processing methods and through the development of products and processes for utilizing residues. So effective has this research been that despite the growth of the nation's economy and two world wars, the nation was supplied with vast amounts of critical wood materials without significantly increasing the rate of harvest in our forests.

Although the national supply of timber has been aided by imports, the conclusion is inescapable that wood utilization research has been highly successful in its efforts to extract additional useful products from the harvested forest. Utilization went from roughly 35 percent of the log in 1900 to nearly 100 percent in some well-managed, integrated mills in 1980. Furthermore, the research provided ways of coping with drastic changes in the character of the material produced by the forest: smaller trees, lower quality, different species, dead trees, and forest residues.

These are impressive accomplishments of wood utilization research, and the Forest Service has made major contributions to these achievements. What about the future?

After dealing with the past and the present, this report addresses the future with the following questions, particularly as they apply to Forest Service research in wood utilization.

-- With all the knowledge about wood accumulated systematically during the past 80 years, why do we need any more?

-- Who is the ultimate beneficiary of the research?

-- What major wood-related problems exist, or can be anticipated in the future, that cannot be solved by applying currently available information?

-- What resources will be needed in scientists and in facilities to continue Forest Service involvement at an appropriate level?

-- How can productivity of the Research Work Units be improved?

-- What subject areas and types of research are most appropriate for future forest products utilization research in the Forest Service?

-- In what disciplines does our scientific strength lie?

-- How do the research roles of industry, universities, and Forest Service differ?

To facilitate reading, some topics covered in abbreviated form in the body of the report are discussed more fully in the appendix under similar headings. This applies particularly to sections dealing with history, accomplishments, and coordination. The sections on the purpose of utilization research and the role of universities and industries arise from Appendix A, which deals generally with the topic of utilization research in the United States.

Although the appendices may have more limited readership, they contain useful reference material and some provocative thoughts on research objectives and responsibilities.

THE PURPOSE OF FOREST PRODUCTS UTILIZATION RESEARCH

IN FEDERAL LABORATORIES

In the Federal government, research on forest products is concentrated in the Forest Service, but other agencies, such as NBS and DOD, are also active. In the Forest Service, the major laboratory, with national and international scope, is located in Madison, Wisconsin. Other laboratories with regional scope are located at seven Stations. However, research findings often have national and international application. The main mission of these laboratories is to provide options for improved forest management decisions on timber removals, to provide knowledge of wood properties, to improve performance of wood in service, and to increase yields of useful products from harvested trees.

The need for the U.S. Department of Agriculture, Forest Service to engage in research on wood and wood products stems largely from its role as manager of a large share of the commercial forests that produce timber for structural purposes, fiber for pulp and paper products, and cellulose and other chemicals for fabrics, plastics, and liquid fuels. In addition, the Forest Service has the major federal role in supplying information for managing all of the nation's forests in the public interest, regardless of ownership.

Since species and growth conditions in the forest determine wood properties, any wood research dealing with these factors is a necessary part of forestry research and forest management. Because of the trend toward shorter rotation tree crops, there is an increasing need for closer coordination between utilization, tree production, and harvesting technology.

The interaction of wood research and forest management has produced some useful relationships in the past, such as those dealing with juvenile wood, rate of growth, density, and fiber length. Increasing sophistication in the techniques of science will result in many other useful relationships in the future. These might well include structural as well as chemical changes in the wood to be achieved through genetics and silvicultural treatments. These are long-term goals of wood research.

Other important goals of wood research deal with the changing forest situation, and have immediate application. The most dramatic changes now in progress are the decline in quality and quantity of western softwoods, the rise of the southern pines, and the rapid increase in volume of mixed hardwoods in the eastern states. In addition, there are millions of acres of slow growing, low-quality stands of mixed hardwood which require new utilization strategy as a first step in more profitable forest land management. Furthermore, there are millions of tons of residues left in the forest after logging awaiting the development of efficient methods for recovery and utilization. These continuing changes in the forest, along with an inevitable increase in future demands, force a continuing program of research to characterize the changes in wood properties, and to determine the effect of these changes on conventional products and processes. For the Forest Service to manage National Forests effectively and play a leadership role in forestry, it should conduct such research in anticipation of future needs, thus forestalling hardships in forest management, in industry, and in the marketplace.

The Forest Service obligation to optimize the productivity of the forest can be fostered in two ways: First, by developing and applying techniques to increase the rate and quality of growth of forest trees; and second, by developing and applying techniques for increasing the yield of useful products from each acre harvested. In the first instance, techniques developed are applied by the Forest Service, and other forest owners, while in the second instance, research results must be transferred to industry for adoption. Once adopted, however, the net effect is the same as adding more growth to the forest.

An important national concern is the fact that the supply of high quality wood suitable for structural purposes is on the decline. When the pent-up demand for new housing is released, there will be an urgent need for those technologies which can immediately extend the timber supply. Technologies for increasing growth, though essential and very effective, will require many years before beneficial effects can be felt in the supply line. Improvements in utilization efficiency, on the other hand, can be applied quickly and, in any case, will be needed even when optimum growth efficiencies are achieved and put into practice. Both will help forest products keep pace with the growth in the economy and will continue to provide an ideal material for construction.

In order to sharpen the focus on the need for utilization research, it is necessary to distinguish between sawtimber and wood biomass. As the supply of timber capable of producing structural materials diminishes, the first casualties will be the prime products--construction lumber, and plywood. Pulp and paper, and reconstituted wood materials are less affected by such changes because size and shape of the tree are less important.

The specific challenge of wood utilization research, therefore, is to find ways of extracting more prime products from a softwood saw timber supply that is shrinking in both quality and quantity, and also to find ways of converting the more plentiful wood biomass into equivalent prime products. A new concept of the wood supply system may be necessary to provide specific raw materials for expanding pulp and paper, particleboard, fuelwood, and chemical industries. Short-rotation intensive-culture plantations offer one viable solution to the supply problem. Progress in the direction of total biomass utilization and conversion is already underway in the form of new volume measurements, whole logging and tree chipping, and utilization of formerly unused bark and wood for flakeboard panels, paper, fuel, and chemicals. According to forest statistics, the removal of timber from the forest is equal to about one-third of the growth in total wood biomass.

Utilizing the wood biomass effectively for any purpose also involves problems of collection, beneficiation, and the use of mixed species. These are problems without precedent. To convert such raw material into structural products will require the development of new fundamental principles and concepts for taking wood apart and putting it back together again. This task also is already underway, but, except for pulp and paper, the relevant fundamental knowledge is not yet organized for efficient use, and the essential analytical work of engineers has only just begun.

THE ROLE OF UNIVERSITIES AND INDUSTRIES

Research in forest products is conducted at universities, and wood industry laboratories, in addition to federal laboratories. In regard to universities, programs of forest products research are carried on in those colleges or departments of forestry that maintain a special curriculum in wood science and technology. These number about 26 at the present time. Some programs are in colleges of engineering, or in schools for pulp and paper technology, chemistry, and biological sciences.

Although several universities have established fairly large wood research laboratories, most university programs are small and limited in scope. As a general rule, universities conduct fundamental research, but significant amounts of applied research and development are also carried on. Graduate students are usually involved in university research programs, and the research tends to be influenced by student needs in regard to timing and scope. However, the quality of the research is controlled by the major professor. University research in forest products is supported partially by institutional funds, and partially by funds from industry and government agencies.

Research by the wood industries as a whole has traditionally been quite modest compared to other industries. Some of the larger companies carry on substantial research programs which are highly applied and developmental in nature. The main thrust is to solve immediate problems, or to develop new products or processes for their own purposes. Publication of their results is rare. Although the wood industry will continue to depend upon universities and government for its research needs, it is important to note that resident technical capability has been steadily increasing. This means that more problems and opportunities will be identified and there will be a stronger industry effort to search for available knowledge and faster adoption of new technologies. It is anticipated that new tax laws promulgated to encourage greater research expenditures, may induce expanded research programs at the more progressive companies. Stronger efforts are required by the Forest Service to cooperate with industry--particularly to share funding of projects at the development and application end of R&D.

In simplified terms, the contrast in the objectives of these three sources of wood research information provide a rationale for the whole. The university with major interest in academic pursuits, fundamental knowledge, and service to its own state; the industry with major interest in applications and immediate profits; and the government with major interest in efficient short-term and long-term utilization of a valuable, but limited national timber resource, combine to provide a stable base for progress in the public interest.1/

1/ The ideas expressed in this report are in general agreement with those expressed in the "Annual Science and Technology Report to the Congress: 1981," Office of Science and Technology Policy, in cooperation with the National Science Foundation. See pages 24 and 25, "The Role of Federal Laboratories" (photocopy Appendix F).

BRIEF HISTORY OF FOREST PRODUCTS UTILIZATION RESEARCH IN THE FOREST SERVICE

Research in forest products became a recognized activity in 1880 when shortages of certain preferred species began to appear. In response to this problem, the Bureau of Census in the Department of Interior and the Division of Forestry in the Department of Agriculture established testing programs to develop information on a wide variety of species. Private laboratories and a number of universities were commissioned to assist in this program. Soon the program was expanded to include wood preservation, wood chemistry, and naval stores, all at separate locations. When problems of coordination appeared, a central laboratory was proposed. Fears of a timber famine arose at the turn of the century, and Chief Forester Gifford Pinchot foresaw that more efficient utilization was the key to forestalling serious problems in the forest.

These two events, coordination of scattered research program, and the stark threat of a timber shortage, led to the establishment of the Forest Products Laboratory (FPL) at the University of Wisconsin in 1910. The first such in the world, it provided an inspiration for other nations to do likewise. It also inspired colleges and universities to give serious attention to both academic and research programs dealing with wood. These remain as outstanding side-benefits of Forest Service leadership in wood research, putting total benefits on a steep exponential scale from the very beginning of organized research in this field.

The program at the new Forest Products Laboratory was quickly expanded to include research on wood-moisture relationships, and this fundamental work led to the first practical dry kilns. World War I produced an urgent need for greater volumes of reliable aircraft wood, a task involving knowledge of wood structure and properties. The War also spurred research on glues and on plywood, which laid the groundwork for the birth of the plywood industry--a major segment of the wood industry today. Research in packaging was also initiated during these early years, from which both military and civilian standards arose for safe delivery of goods of all types, including foods.

The period between the two world wars continued the upward spiral of research growth and produced information which led to the discovery of new wood preservatives, new pulping processes, new concepts for house construction, and the formulation of design principles for laminated timbers, to name a few. Also during this period, the FPL moved into its present building with greatly increased working space and improved facilities.

World War II saw the FPL staff increase to 700 as it sought to provide the nation with wood substitutes for many exacting applications formerly served by metals. A major effort again focused on aircraft, plywood, drying, and packaging. Gluing technology received a significant boost.

Since World War II, the FPL has continued to accumulate basic information on strength properties of wood with a view toward improved grading systems and more precise design criteria for structures. Work in reconstituted wood products was initiated to find ways of utilizing waste wood and to improve properties and performance of these materials.

A significant post-war development was the establishment of the Forest Utilization Service (FUS) to promote the application of research results. Units were established at eight Stations and their work not only solved field problems quickly, but also contributed to the research program as well. The FUS has since been replaced by a system of State and Private Forestry and by research RWUs at seven Stations whose programs are coordinated through the Director for Research in the Washington Office..

EXAMPLES OF ACCOMPLISHMENTS

Major breakthroughs have occurred in each area of research over the years. The following are examples of accomplishments that reveal the scope of the program and the value of the discoveries. (Additional examples are presented in Appendix C). Although value in dollars is not easy to estimate, it will be apparent that a number of projects have each yielded benefits far in excess of the total cost of all forest products research since 1900.

More important, however, is the fact that these and many other discoveries and developments have resulted in enormous savings of wood. They have enabled the nation to maneuver through drastic changes in the character of the timber supply, and to provide the technology needed for wood to assume a major role in two world wars. Discoveries dealing with higher yields from each tree harvested, combined with improved design of wood structures and improved protection systems, have enabled the forest managers to adhere to the principles of multiple-use and sustained yield. Forest statistics indicate a fairly uniform rate of timber removals since 1900, yet the population has tripled since that time. Although metals, plastics, concrete, and masonry have helped to ease the pressure on the forests, advances in wood science and technology have contributed substantially to the goal of sustained yield.

Much research is intended to produce benefits for society other than savings in the use of wood. Some of the major breakthroughs have resulted in new applications and new markets where the properties of wood could be used effectively. Other research has led to improved safety of wood structures, increased service life, and reduced cost to consumers. It is important to note the concomitant interplay of wood research implied in these statements, i.e., some research expands the demand and some research reduces the demand.

Seasoning--Background information developed on wood-moisture relationships led to the development of the first practical dry kiln at the Forest Products Laboratory in 1914. This reduced the time for drying lumber from months to days, and permitted greater precision in dealing with lumber dimensions. The FPL and Station research on kiln schedules for each species provided the standards for lumber drying. Today, virtually every company producing wood products operates one or more dry kilns.

Preservation--Early research in wood preservation resulted in the use of nondurable species for crossties for the expanding railroad system of the nation in 1900. This removed the pressure on white oak which was already in short supply because of the demands of the railroad industry. Preservative treatment not only allowed many other species to be used for this critical purpose, but they also lasted longer, thus balancing harvesting operations

among species, while minimizing the drain on the forest. New preservative materials and new processes have been developed to greatly increase the use of wood in adverse environments, e.g., docks, decks, bridges, utility poles, and more recently, wood foundations for buildings.

Pulp and Paper--The development of the Neutral Sulfite Semi-Chemical (NSSC) pulping process at the FPL opened up the hardwood timber resource for use in paper products. It was widely adopted and it reduced the drain on softwoods. Other processes are being developed which will further expand the use of hardwoods for pulp and paper, thus conserving softwoods for other uses.

Laminated Timber--Early research on adhesives and on the phenomenon of adhesion led to the discovery of durable adhesives and to methods of producing reliable bonds that perform satisfactorily for many years. The laminating industry grew rapidly when this information became available and provided outstanding wood structures for large commercial and other buildings. FPL research provided the basis for effective processing and engineering of laminated structures.

Plywood--Plywood, unknown as a commerical material in 1900, is now a major industry, consuming about 12 percent of the harvested timber. It is one of the principal items of wood construction and furniture manufacture. Its use greatly improved the quality of homes and other structures from the standpoint of performance and longevity. Results of early research at the FPL helped to inaugurate and establish the plywood industry. More recent research at both FPL and the Southern Station developed key information that permitted the use of southern pine for plywood, and the Southeast Station has developed hybrid plywood panel products that are now being manufactured commercially.

COORDINATION OF UTILIZATION RESEARCH

Coordination of utilization research programs in the Forest Service is the primary responsibility of the Deputy Chief for Research, assisted by the Forest Products and Engineering Research Staff in the Washington Office. However, field research managers are responsible for interchange of information and cooperation between RWUs conducting utilization research. The coordination issue is a primary subject of all field program reviews held regularly by the Washington Office Staff.

Formal mechanisms have also been developed to assure coordination with industry and universities. Annual meetings are held each October with university representatives and each February with industry to discuss program directions down to the research study level. User groups and scientists from university and industry participate in reviews of RWUs and problem selection meetings. This coordination (explained more fully in Appendix D) has been very successful in developing research programs, eliminating inadvertent duplication of effort, and has multiplied the benefits from the research.

CURRENT AREAS OF RESEARCH AT FOREST PRODUCTS LABORATORY AND EXPERITMENT STATION BY SUBJECT

About 70 percent of the Forest Service utilization research resides at the Forest Products Laboratory. The remainder is distributed among seven of the Forest and Range Experiment Stations. There is no utilization research conducted at the Pacific Southwest Experiment Station and at the Rocky Mountain Station.

It is important to distinguish between the program efforts at the Forest Products Laboratory and the Stations. In brief, the Forest Products Laboratory has national responsibilities while the Station programs concentrate primarily on regional wood utilization problems. However, in practice, research results, regardless of source, may be used regionally, nationally, or internationally. A better focus on this difference can be made by citing examples of work underway in each major program area at the various units. The distribution of scientists efforts is given in (table 1)*. (A brief description of current programs by Stations is given in Appendix E.)

Processing of Lumber and Wood Products (FPL, NC, NE, SE, SO)--This area of research includes methods for improved recovery of lumber, veneer, and other products from logs; development of concepts for new structural products from low-quality hardwood; development of principles for improving the properties of composite wood products; analysis of processes for reduced energy uses; and analyzing drying techniques to increase the grade and reduce drying time.

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*Data on personnel cited in this report was based on the Directory of Projects, Forest Products and Engineering Research.

Table 1.--Current distribution of scientist effort in various utilization research program areas. Estimate of SY effort by Station

Utilization research program areas	Forest Experiment Stations							
	Pacific Northwest	Inter-mountain	North Central	North-eastern	South-eastern	Southern	Forest Products Laboratory	Total
Processing of lumber and wood products			3	4	4	3	16	30
Adhesives					1/2	1	6	7 1/2
Chemicals and energy from wood	1				1		8	10
Pulp, paper, and packaging							18	18
Construction materials properties and fire safety					1 1/2	1	24	26 1/2
Protection of wood						*	12	12
Biodegradation							3	3
Wood Anatomy and tropical wood utilization							4	4
In-woods processing for improved utilization		4						4
Biomass characterization and measurement for forest product recovery	7		1	3	3			14
Totals	8	4	4	7	10	5	91	129

*In addition, there are five SYs at SO and three SYs at FPL supported by FIDR.

At the North Central Station the effort is aimed specifically at machining and drying of high-quality hardwoods. Notable recent achievements include improved solar-drying techniques and abrasive planing that reduces waste.

The Northeastern Station is concentrating its efforts on ways to convert low-quality hardwoods into high-value panels and boards that can be used in the cabinet and furniture industries. They have completed an intensive series of studies that have resulted in a new sawing and machining system to accomplish this goal.

The Southeastern Station is conducting research on composite products for structural applications. These products involve a veneer face with particle core and are generically referred to as COM-PLY. There are now four plants that produce COM-PLY panels--one of which was a direct result of the research effort on southern pines. These panels are designed to substitute for structural plywood. Another form of COM-PLY still under development will yield material equivalent to structural lumber. These products can utilize forest residues and low-quality mixed hardwoods which will improve forest management practices.

The Southern Station is conducting research on defect sensing to improve the yield of clear wood cuttings from hardwood lumber. In addition, they are conducting research on particleboard aimed at utilizing residue and low-quality hardwood trees which are now generally knocked down and burned prior to pine regeneration. As a result of the research, a $30 million panel plant is being built in Louisiana.

At the Forest Products Laboratory, research activities range from improved techniques for sawing and peeling wood, to new technologies for producing high-quality composite materials. Recent achievements include a technique to increase the yield of veneer from logs and a method for decreasing pressing time for composite products by more than 50 percent. These and other results of the research will save millions of cubic feet in wood resources.

Adhesives (FPL, SE, SO)--This research is aimed at improving the performance of conventional resins, developing adhesives from petroleum substitutes, finding techniques to improve bonding, and controlling degradation of wood in the bonding process. This is an extremely important area of research. It is certain that the nation will rely more heavily on composite wood products as consumer demand increases and our resource base of large timber declines. This will require large quantities of adhesives. Currently, adhesives represent 4 to 6 percent of the total weight of a composite product, yet they can represent over 25 percent of the cost. These costs will continue to rise with petroleum costs. Efforts to find substitutes must be expanded. The majority of this work is conducted at the Forest Products Laboratory. In addition, the Southern Station has basic research underway aimed at producing high-quality adhesives from southern pine bark, and the Southeastern Station has research underway to develop adhesives from agricultural residues.

Chemicals and Energy from Wood (FPL, PNW, SE)--Chemicals have been made from wood for several centuries. The use of wood for this purpose declined drastically with the abundance of inexpensive petroleum. A renewed interest evolved with the rising cost of oil. The focus of the current research is to

recover valuable chemicals from pulping byproducts, improve hydrolysis techniques to increase the yield of alcohol from wood, find more efficient wood gasification, combustion, and pyrolysis processes, and use microbial techniques for isolation and recovery of chemicals.

Effort at the FPL in energy and chemicals includes microbial technology, chemicals production, naval stores, and energy-efficient processing. At the Pacific Northwest and Southeastern Stations, there is research on the measurement and utilization of total forest biomass.

Pulp, Paper, and Packaging (FPL)--All Forest Service research in pulp, paper, and packaging is conducted at the Forest Products Laboratory. More than one-half of all timber harvested goes into the manufacture of pulp. Softwoods are currently the preferred or only species that can be used for high-strength paper products. A major objective of the research is to find ways of utilizing hardwoods for high strength papers to alleviate the pressing demand on softwood resources. A current product of research is the new Forest Products Laboratory Press Drying Process which permits the use of hardwoods in paperboard for corrugated boxes, a high volume industry, and a major user of strong papers. Completed pilot studies show that paperboard with properties and yields superior to current softwood-based processes is possible. This promises to be the biggest breakthrough for pulp and paper in the past 30 to 50 years.

Construction Materials Properties and Fire Safety (FPL, SE, SO)--The safe design of wood structures in the United States is based most heavily on the basic engineering research conducted by the Forest Service. A wide variety of research is underway to build upon our knowledge of wood properties and performance. This work is extremely important as we begin to utilize more products from fast-growing young trees that are replacing old-growth timber. Design standards for the future must economize the use of wood to meet cost restrictions, and to accommodate new concepts of reliability for structrual performance. Efficiency in the use of woods in structures is also a powerful conservative measure which can effectively extend our timber supply.

Areas of current research include: assessment of mechanical properties of structural lumber, prediction of load carrying capacity of composite structures, improved thermal/moisture design and performance, prediction of load carrying capacities for fire-exposed assemblies, improved reliability-based design techniques, and development of design criteria for fire safety of wood structures.

The Southeastern Forest Experiment Station is conducting research on fasteners and glues for housing components, and the Southern Forest Experiment Station is evaluating properties of southern hardwoods and composite products.

Protection of Wood and Biodegradation (FPL, SO)--Protection of wood from destructive microorganisms and insects is essential to the conservation of forest resources and replacement costs imposed the user. Many chemicals have been used in the past that were extremely effective, but are now known to create environmental hazards. Some have been dropped from use and others restricted. The current research is aimed at finding new concepts and procedures for safely preserving wood from biological degradation. Research on methods for protecting wood from marine borers, fungi, bacteria, and from ultraviolet light, is conducted at the Forest Products Laboratory. Research on methods for controlling subterranean termites and wood destroying beetles is conducted at the Southern Forest Experiment Station.

The primary thrusts are: research on fundamental mechanisms of decay leading to new approaches to preserve wood, development of environmentally sound methods to control termites, evaluation of existing preservatives, and treatment to improve exterior finish performance.

Wood Anatomy and Tropical Wood Utilization (FPL)--The Forest Products Laboratory has the world's largest research collection of wood samples. It is an international source of information on basic wood characteristics. Wood users, from home builders to furniture manufacturers, are dependent upon basic knowledge developed on thousands of wood species.

The research program in wood anatomy includes the development and implementation of an international computerized wood identification system, and development of information on the anatomical features of domestic and foreign wood species for wood identification purposes. Tropical wood utilization includes the evaluation of foreign woods as substitutes for domestic species, and analyzing properties with respect to processing techniques. All of this research effort resides at the Forest Products Laboratory.

In-Woods Processing for Improved Utilization (INT)--The entire effort in this area is at the Intermountain Station. Special regional problems dictated the need for the research. In the Intermountain region, serious land management problems exist where forest of small-sized timber occur on steep terrain. Production of large high-value trees is impeded by lack of markets for small stems. Also, at the Intermountain Station a systems approach, "stump-to-mill," is under study to find least cost methods for harvesting and processing these small, inferior trees.

Biomass Characterization and Measurement for Product Recovery (NC, NE, PNW, SE)--Research is underway at four Experiment Stations aimed at measuring and determining the best utilization opportunities for a variety of marginal species.

Billions of board feet of timber have been killed in the West by catastrophic events such as insect epidemics and windstorms. Research at the PNW Experiment Station has shown that substantial portions of the dead timber can be used for conventional products, but to maximize opportunities, the relationship between time-since-death, tree size, species, and types of products produced must be understood. Although log or tree grades have been developed for five of the most important western softwood species, work continues on other important species. Basic product recovery information is required by public agencies for timber appraisals and is used by private industry to optimize log allocation decisions.

The Northeastern Station is evaluating the product potential and values for eastern hardwoods. Again this research forms the basis for assessing timber values. As part of a program on developing short-rotation intensive-culture plantations, the North Central Forest Experiment Station is evaluating the properties of wood, bark, and leaves from young trees, and the use of this raw material in specific reconstituted products.

At the Southeastern Station studies to determine total biomass are underway. The primary thrust at this time is to quantify the portions of the forest that can be used for energy. This is a strong cooperative program with the State of Georgia that has utility throughout the South. Previously completed efforts provide data on multiproduct options for many of the important southern species. Additional work is underway at the Southern Station in connection with biomass harvesting methods.

BUDGET AND EXPERTISE

Budget The Forest Service research appropriation, based on 1977 dollars, has been relatively constant between 1977 and 1981 (table 2). The most significant increase came in 1981. The outlook for the future reflects rather substantial decreases in the ability to fund research. If this trend continues, it becomes increasingly important to analyze utilization research programs carefully and to establish priorities so the most urgent problem areas are addressed.

Accompanying the budget decreases has been a reduction in the number of scientists to conduct the research. Since these reductions often eliminate a critically needed discipline, it will be necessary to continue to take advantage of opportunities for extramural research programs with universities to complement our in-house expertise. In the period between fiscal years 1977 and 1981 forest products utilization research has spent about 8.4 percent of its allocation in extramural research (table 3). This percentage is lower than the Forest Service research average.

Table 2--Trends in appropriation levels for total Forest Service and forest products utilization research 1977 to 1982

Year	Fixed weighted price index1/ (1972 weights)		All research		Forest products utilization research	
	Value	Index	Allocation	Adjusted to 1977	Allocation	Adjusted to 1977
			1,000 dollars			
1977	142.9	1.000	87,927	87,927	11,800	11,800
1978	153.7	1.076	108,166	100,526	12,555	11,668
1979	165.1	1.155	110,790	95,922	13,518	11,704
1980	(183.9)	1.287	111,531	86,660	15,342	11,921
1981	(205.9)	1.441	127,812	88,696	18,575	12,890

1/ Economic report of the President. Transmitted to Congress, 1982. Table B-3. Implicit price deflators and alternative price measures for gross national product and gross domestic product 1929-1981. U.S. Government Printing Office. Washington, D.C.

Table 3--Allocation of funds for extramural research in forest products utilization by year and percent comparison with total Forest Service budget

Year	Forest products utilization research		Percent of appropriation in extramural research for	
	Appropriation	Extramural research funding	Forest products research	Total Forest Service research
	- - - 1,000 dollars - - -			
1977	11,800	697	5.9	8.8
1978	12,555	1,521	12.1	9.4
1979	13,518	960	7.1	9.9
1980	15,342	1,128	7.4	9.6
1981	18,575	1,948	10.5	11.0
Total	71,790	6,254	8.7	9.8

Expertise--From 1977 to 1981 the total number of scientists (GS-11 and above) in the Forest Service numbered about 950. During the same time, scientists in forest products utilization research numbered about 130. It is expected that there will be a significant reduction in both of these figures in the next few fiscal years.

An analysis of professions in forest products utilization research, including professional support personnel, shows a total of 155 professional people who have degrees in 18 different disciplines (table 4). Included in the table are assistant directors and several important supporting scientists, such as plant pathologists and plant physiologists, who work closely with other utilization scientists. Not included are a number of statisticians who represent a key professional support group, and some technicians with college level degrees.

Table 4.--Professional disciplines by grade level and terminal degree--Forest Products Utilization Research

Code	Professional discipline	GS-11 and 12				GM-13 and 14				GM-15				GM-16+				Totals			
		BS	MS	PhD	Total	BS	MS	PhD	Total	BS	MS	PhD	Total	BS	MS	PhD	Total	BS	MS	PhD	Total
0808	Architect					1			1									1			1
0430	Botanist	1			1			1	1			1	1					1		2	3
1320	Chemist	5	4	3	12			8	8			1	1					5	4	12	21
0893	Chemical Engineer	2			2	3	1	4	8			1	1					5	1	5	11
0334	Computer Specialist	1			1													1			1
0414	Entomologist							1	1		1	1	2						1	2	3
0460	Forester	1	3		4	2	3	2	7			1	1					3	6	3	12
	Market Analyst		1		1														1		1
	Meteorologist		1		1														1		1
1380	Forest Products Technologist	6	11	3	20	3	22	10	35	2	1	1	4			1	1	11	34	15	60
0410	General Biological Scientist										1	3	4						1	3	4
0810	General Engineer		7	3	10	4	4	4	12		2		2					4	13	7	24
0430	Microbiologist	1			1			1	1			1	1						2	1	3
0806	Materials Engineer	1			1	1			1									2			2
0830	Mechanical Engineer					1			1									1			1
1310	Physicist		2		2														2		2
0434	Plant Pathologist							3	3											3	3
0435	Plant Physiologist							2	2											2	2
	Totals	18	29	9	56	15	30	36	81	1	5	10	17			1	1	34	66	55	155

The Forest Products Technologist series is the most common with 60 scientists. This is followed by 32 chemists and chemical engineers and 27 general, mechanical, and materials engineers. These six classifications make up 79 percent of utilization research staffing. Table 4 also shows that Forest Products Technologists and General Biological Scientists are predominant in the higher ranks.

It is noteworthy that there is only one scientist in the GM-16 grade and above. This suggests either that there are no other scientists qualified to work at this level presently in Forest Products Utilization Research or that the promotional system is failing to recognize scientists who are qualfied. Another possible interpretation is that problems of high complexity are not being addressed by FPUR scientists. In any case, this matter of grade level requires attention if FPUR is to maintain a leadership position in this field of research.

Omission of the statistician category from the listing of disciplines in table 4 appears to be an aberration of the classification system, or of the reporting and records system. For some reason, they were not included in the same source of information of disciplines, or in scientist-year assignments, as were the other disciplines. Considering the importance of these professional people in the quest for efficient and reliable research results, some changes may be necessary to assure proper recognition of their contribution to FPUR programs.

Thirty-five percent of the FPUR scientists have Ph.D.'s. By comparison 44 percent of all Forest Service researchers hold Ph.D.'s. Of the 53 Ph.D.'s in Forest Products Utilization Research, 16 are Chemists and Chemical Engineers, 14 are Forest Products Technologists, and 7 are General Engineers. The rest are distributed over eight other disciplines.

Currently, the average age of Forest Service scientists is 43.2 years. A total of 311 are over 50 years of age. The age profile for forest products utilization research is proportionate. Therefore, we can expect that a number of openings will be available over the next 5 to 10 years. Strong efforts should be made to recruit Ph. D.'s and young, promising scientists with adaptable skills as opportunities arise for filling research positions. Some scientists can provide a fresh influx of new ideas early in their careers, while others require years of work before full performance can be achieved. This emphasizes the need to continue recruiting young scientists to maintain the vitality of research programs. Advanced training for scientists to develop specific skills should be maintained at the highest possible level.

PRODUCTIVITY OF UTILIZATION RESEARCH

The measurement of utilization research productivity is a difficult task. The best measure is a hindsight analysis of the impact of a given area of research after the results have been implemented many years later. Then, at a given point in time, after the adoption of a research idea, one could measure the results in concrete terms, such as volume of timber saved. However, even this has proved difficult to do because of the ramifications in the use of research results, and because of shared credits with other inputs to the particular successful event under study. Unfortunately, despite the difficulty, research managers and their scientists must estimate the benefits that will be derived from successful solutions to an avenue of research. Further, the research manager must have methods to measure outputs of individuals and research units.

The Forest Service uses an annual attainment report for this purpose. This report is prepared by all Stations and contains the number of attainments, such as publications, patents, speeches, etc., of each scientist.

One of the primary measures used in evaluating productivity is the number of publications. FPUR produced two publications per scientist-year over the 5-year period of 1977-1981. This compares to the overall Forest Service average of 2.1 (table 5). The average number of publications per year for individual scientists ranged from 0.2 to 10.4, including sole and joint authorships. This is an exceedingly wide range. Some scientists had no sole or senior authorship paper during this 5-year period, a situation that impedes the opportunity for rapid professional advancement. On the other hand, it should be recognized that the trend toward work on complex problems with a team approach may limit sole authorship. The number of publications per scientist year (5-year average) also varied widely by RWUs, ranging from 0.50 to 3.19. This excludes one project that was only recently chartered.

Forest Products Utilization Research

Table 5--A comparison between Forest Products Utilization Research and Forest Service Research publication costs (Includes how-to-do-it papers and papers published in proceedings)1/

Year	Scientists No.	Pubs.	Appropriation ($1000) Pubs./Scientist	Cost/Pubs. ($1000)
1977	303	130	11,800 2.3	38.9
1978	294	129	12,555 2.3	42.7
1979	207	125	13,518 1.7	65.3
1980	189	131	15,342 1.4	81.2
1981	266	130	18,575 2.0	69.8
Total:	1259	645	71,790 2.0	57.0

Forest Service Research

Year	Scientists No.	Pubs.	Appropriation ($1000) Pubs./Scientist	Cost/Pubs. ($1000)
1977	2421	949	89,927 2.6	37.1
1978	1780	968	108,166 1.8	60.8
1979	1954	942	110,790 2.1	56.7
1980	1892	964	111,531 2.0	58.9
1981	2010	957	127,812 2.1	63.6
Total:	10,057	4780	548,226 2.1	54.5

1/ Data obtained from the annual Reports of the Forest Service.

The analysis did not include a measure of quality on each publication, again, because of the difficulty of evaluating this factor with the proper degree of fairness. However, the analysis did include an evaluation of other activities such as the number of technical assistance events and workshops. While some projects had rather low publication records, they were quite involved and successful in technology transfer efforts. This is commendable, but it should be recognized that a unit whose mission is research should strive for a proper balance so that scientists can be assured of an optimum rate of professional growth.

It is incumbent upon the research managers to analyze the individual and RWU productivity carefully to determine whether full value is returned to the public for appropriated funds. This has been a continuous and dedicated function of the research manager in the past. Some research units have improved greatly over the past 5 years. However, even stronger efforts must be exerted in the future to further improve the productivity of low performing individuals and units. The importance of this task is more evident with the current budgetary constraints. As we place priorities on future efforts, we must consider the expertise and the unit productivity to accomplish the most important research assignments. Research managers will need to favor those projects which have the most urgent goals, and which also have the proper expertise and a good productivity record. It may well be necessary to change the mix of scientists in some projects to solve particular problems and to improve overall productivity.

FRAMEWORK FOR FUTURE RESEARCH

The foregoing brief description of the utilization research programs at the Stations and the Forest Products Laboratory provides a status report on current research emphases, budget trends, personnel, and productivity. These represent the Forest Service utilization research goals and resources for short-range planning. All plans involving these programs have been fully reviewed, coordinated, and approved. However, it is just as important to apply our best thinking and knowledge to the long-term areas of emphasis. The following discussion represents a viewpoint in that direction.

The historical and traditional mission of forest products utilization research is sound and should not change. We should continue to: (1) provide a basis for the most effective use of wood and wood-based products; (2) provide more options for utilizing all species and qualities of wood to improve forest management and to extend the use of the nation's timber resources; and (3) provide expertise on all scientific and technical aspects of wood to assure maximum yield from harvested trees and to assure optimum performance of wood products. This mission must be kept in mind when reviewing the status of our programs and when establishing broad goals and objectives for the long term.

The direction of forest products utilization research is influenced by many factors. For example, there is pressure from a variety of manufacturing companies to work on problems common to the products they produce. There is pressure from the construction industry and equipment manufacturers. In addition, a number of trade associations have special interests. From another

direction, we find that several other federal agencies rely on Forest Service research to assist them in their programs. Consumer groups and landowners are interested in basic information about wood and its potential uses. Lastly, many foreign countries rely on our utilization research and on our outputs of fundamental knowledge of wood.

While these pressures are operating, often simultaneously, the Forest Service must make its best case in competing with other agencies for limited federal research funds. It is obvious that the problem areas of wood utilization are increasing as uses of wood become more sophisticated. However, it is impossible for the Forest Service to seek funding to work on all of the problems presented to them. Other avenues must be pursued where the combined efforts of interest groups, industry, universities, and federal laboratories can coordinate and share the effort.

More than ever before the scientists and research administrators will have to draw user groups into the research planning process to assure that innovations are adopted. This aspect of cooperation should be considered in all phases of planning from the problem analysis through to the individual study plans, particularly when the intended research result is known to have immediate utility. Advisory committee meetings, trade association and professional meetings, and individual visits should be used to link implementation of research in cooperative agreements with the user.

The strategy for the future should be to concentrate the research efforts within the various program areas on ventures where major advances can be made in utilizing currently neglected wood resources, such as, logging residues, low-quality hardwood, and dead trees. Further, these efforts should concentrate on the efficient use of wood, particularly in structural applications, and pursue basic knowledge that will permit maximum outputs of the higher valued products. Eight broad areas for concentrated effort are proposed.

(1) Concentrate research on structural composite products to studies that lead to better understanding of basic mechanisms and principles of raw material qualities, mechanics and chemistry of formation--including adhesives and adhesion--engineering properties and design criteria, and durability against adverse environments and fire hazards.

Structural composite materials have already received acceptance as a building material and have great promise for the future. However, the full potential of the possibilities of combining particles, flakes, fibers, and veneer cannot be reached without a coordinated effort to discover basic relationships between the various wood elements and all the other factors in the boardmaking process.

One of the most important areas of study is adhesives and adhesion, first to minimize the cost of an expensive ingredient, and the second to reduce the energy requirements in the bonding process. Also, new nonpetrochemical adhesive materials must be found, possibly from lignin or bark; new concepts and principles for bonding must also be developed.

Since these materials are destined to be used in engineered structures, they will need the same sequence of authentic establishment of properties and design parameters as for lumber and plywood. This task should begin soon. In addition, research on protection for use in adverse environments must be initiated, including decay, insect, and fire resistance. Opportunities for improved dimensional stability should also be investigated.

An ideal opportunity for Forest Service leadership in this area of research can be fashioned by moving toward a materials science approach in which composition, structure, and processing variables are manipulated to achieve a predetermined set of properties. These property goals should be proposed by engineers who are themselves doing research on innovative design of structures.

(2) Concentrate research on papermaking to reactions and processes that efficiently convert hardwood and recycled fiber to paper with adequate performance properties, and on facets of papermaking that lead to engineering properties and engineered uses.

Paper research has resulted in the development of a broad array of technologies to convert less-desirable woody materials to higher value products. Advances in pulping, such as NSSC pulp from hardwoods, refining oak fiber for printing papers, and press-drying for stronger hardwood papers, have opened the door to greatly expanded utilization of the total forest output.

About 25 percent of pulp furnish is presently derived from only select domestic hardwoods. Dense hardwoods are generally rejected because of their shorter fibers and the presence of troublesome vessel and parenchyma elements. Research is needed to overcome these limitations through new understanding of the responses of hardwood fiber to new processes and chemical treatments.

Similarly, only 23 percent of our annual production of paper and paperboard is recycled. By presently available technology, the performance of recycled fiber is inferior to that of virgin fiber. A promising area for research is that of obtaining understanding of the causes for degradation by current recycling procedures and developing modified procedures which overcome the deficiency.

Examination of fundamental factors which influence drainage and fiber retention could lead to improvements in rates of liquid water removal on the paper machine and reductions in energy needs for thermal drying. This is an especially challenging area of basic research. Success would have important implications for energy conservation and for reduction in environmental impacts.

(3) Concentrate research on the chemistry and microbial technology of wood to reactions and processes that improve the yield and quality of pulp and chemicals, and reduce energy and pollution loads.

Chemical and microbial technologies are basic to the discovery of new wood-derived chemical and pulping processes that are less polluting and more

energy conserving. Chemical research can provide major new outlets for all types of wood through uses such as fuels, charcoal, animal feed, and carbohydrate and lignin derivatives.

Fundamental understanding of pulping reactions such as the use of anthraquinone, oxygen, and amines may lead to improved high-yield nonpolluting pulping processes. Chemical research has improved processing technology for the production of ethanol, xylitol, furfural, and naval stores from wood. Recent results have demonstrated a greater potential use of microorganisms in purifying polluted wastewater.

Microbial technology is emerging as a broad and very significant research area for low-energy-nonpolluting-chemical processes that offer unique specificity. Chemical modification of lignin, furfural, and other carbohydrates can lead to potential uses in adhesives, polymers, and chemical intermediates.

Research in microbial technology promises to lead to processes for biopulping, biobleaching, pollution control, chemicals, food and feed from wood and wood byproducts. Fundamental research will be concentrated on the biochemistry and physiology of microorganisms with potential in the above processes.

With a tightening supply of petrochemicals it is necessary to learn how to extract all the chemicals from wood possible. Of course, cellulose (chemical pulp), a natural polymer, is the largest volume chemical that is presently extracted from wood. Increased recovery of naval stores, development of phenol production from lignin, and increased use of hemicellulose are all important areas of research on chemicals from wood. The chemical components of wood have the potential to provide a wide range of raw materials for the organic chemical industry.

(4) Concentrate engineering research on basic engineering properties of wood to factors that affect properties such as defects, changing growth rate, duration of load, chemical treatments, and environmental influences.

The basic foundation for all engineering is the design stresses for each material. The safety of structures depends upon the accuracy of these design stresses. Technology of stress grading lumber and development of design stresses has evolved over many years of research. These have served well for use in the deterministic design methods that have historically been used. However, with the introduction of new reliability and performance-based design procedures, the engineering properties of wood and the variability of properties must be more closely defined for these more precise design methods.

Research will concentrate on strength properties by size, grades, and species as now used for structural purposes. Such data will provide the basis for accurate estimation of design properties and for assessment of current technology for visual grading of structural wood products. In the future, for the more highly engineered uses, visual grading technology will not suffice. A combination of visual and nondestructive machine grading technology will be necessary. Such technology is in use today on a limited scale, but for broader use, a new generation of grading technology will be required.

New forestry practices are resulting in rapidly grown trees. Such trees have characteristics different from those grown at a more normal rate and have lower strength properties. Research is required to define properties of these new forests before such material can safely enter the marketplace.

Strength of wood is time-dependent. It is known that a wood member will carry far more load for 5 minutes than it will carry for 10 years. However, this is known only for clear wood in a bending mode. With the advancing design procedures, this time-strength relationship must be more accurately known for all loading modes and for all grade-size-species combinations.

For long-lived structures, preservative treatments are recommended where decay hazards exist. For given levels of retention of some salt preservatives, and for some preservative treatment processes, strength of wood is affected. Research will be directed at determining the effect on strength of treatments and treatment processes. Similar research must also address the effects of fire-retardant treatments on strength.

Environmental influences also affect wood performance in use. The effect of temperature and moisture must be considered by design engineers. While such effects are known for clear wood, they are not adequately known for structural grades of lumber. Such information is necessary in development of engineering design stresses and in the engineering design of structures for varying environmental conditions.

(5) Concentrate research on design criteria to fastener performance, and computerized three-dimensional design models for complete structures to provide more efficient structures, including those using composite materials and unitized components.

For more than 50 years, most of our low-rise structures have been built primarily with dimension lumber framing material covered with some type of wood-based panel product. Our changing timber resource will force a change in the way future structures will be built. New wood materials, components, and systems will be emerging to replace the more traditional construction materials and methods.

Shortages of large logs for wide lumber and plywood will result in: (1) manufacture of building components involving trusses substituting for wide lumber and particle-based panels for plywood; and (2) innovative components from engineered and/or shaped particle materials. In order to assure structural adequacy of these innovative systems, accurate structural analysis and modeling techniques are needed. These structural models can be used to compare the predicted performance of components built with innovative materials to that built with conventional materials.

Research on modeling of three-dimensional full-size structures is needed to quantify load distribution and component interaction to permit more efficient design. This work will be needed to lead the way to defining realistic performance requirements for innovative components. Accurate material property information is a necessary input to these structural models. Properties of lumber and panel products are being developed in related programs.

Information on fasteners is also needed. This is now regarded as the weakest area of knowledge needed to develop realistic models for the performance of structures. Nailed joints are most often used to fasten sheathing materials to framing members to form engineered components and to fasten these components together. The characteristics of nailed joints and other connectors, such as metal plates, are needed to evaluate the behavior of both components and the three-dimensional full structure.

In components such as trusses, structural efficiency is engineered into the systems by subjecting lumber to combined axial and bending loads. Accurate knowledge of the behavior of lumber under combined loading is lacking and must be developed for optimum efficiency in timber design.

New energy efficient construction, and numerous innovative systems have been adapted to wood construction. But these highly energy efficient structures present possible problems in that, under certain conditions, moisture can condense on surfaces and accumulate in structural cavities which causes problems such as buckling of panel products, reduced thermal properties, or in severe cases, decay of the structural members. Research is needed to better and more accurately model both the thermal-moisture interactions and moisture transfer mechanisms in wood construction.

Increased land costs are forcing closer spacing of dwellings, and the importance of fire safety is a growing concern. Computer modeling for fire safety of light-frame wood structures is important in the acceptance of changes in the construction processes. This can have a major impact on the continued acceptability of wood buildings in the future.

(6) Concentrate research on wood protection to reactions and processes leading to safe new wood preservation methods including chemical modification of wood.

Wood protection research is on the verge of revolutionary new methods of protecting wood in adverse environments. Work in this area of research has been ongoing for many years in an effort to improve existing processes. More recently, concern for the environment and human safety has put new emphasis on alternatives for hazardous materials, and on the broader concept of integrated pest management. As a consequence, a number of novel approaches have become exceedingly important. Work on chitin inhibition, a technique that has shown promise with wood-destroying fungi should be accelerated. Additional research is needed to expand the chitin inhibition theory to termites and other wood-destroying insects.

Another novel approach is the use of natural pesticides, some of which occur naturally in certain species of trees and some are produced by trees as a protective reaction at the boundary of invasion sites. These natural chemicals must be identified, isolated, and synthesized before feasibility can be considered.

Chemical modification of wood also offers good opportunities to improve decay resistance, and in addition, can lead to new ways of achieving dimensional stability. Closely related to chemical modification is the problem of chemically bonding preservative materials permanently to the cell walls of the wood and thus greatly improving service life. All three of these research areas draw heavily upon basic knowledge of wood chemistry.

It is now evident that researchers dealing with the biodegradation of wood must work more closely with design engineers to define parameters of design that affect moisture buildup in structures.

(7) Concentrate research on western species to the characterization and product potential of dead and dying timber, logging residues, and hardwoods.

A variety of problems exist that preclude utilization of large volumes of softwood in the Western United States. Lack of utilization potential for small sized material creates costly land management problems following harvest operations. Also, the inability to economically harvest small trees exclude millions of acres of commercial forest land from proper management. A critical issue is the continual loss of trees to windstorms, insects, and disease where the primary control is removal. However, removal cannot occur unless an economic outlet is available.

Although the principal commercial species in the West are confiers, large volumes of hardwoods are underutilized or unutilized (about 1 billion tons of hardwood in 10 billion tons of wood biomass).

A major research effort is needed to develop reliable estimates of volume, character and utilization potential for residues, small timber, and other marginal timber stands. A body of knowledge has been developed in past efforts but only a portion of the total job is completed.

These efforts must be completed in conjunction with indepth studies of alternative methods for harvesting, transporting, and processing. Conversion techniques from forest to mill must be analyzed to determine the most profitable ways of recovering this unused wood resource.

This work, which will be carried out primarily by the Station utilization RWUs, must be coordinated with land managers. It must consider the highest priority land management problems.

(8) Concentrate research on eastern species to the potentials for total utilization, including trees from all types of ownership and site classifications.

The eastern sections of the United States have a variety of utilization problems that adversely affect good forest management practices. Nearly 70 percent of the total forest biomass in the East is hardwood. The growth of these hardwoods exceeds removals by a ratio of 2 to 1. The general quality of the hardwoods is low with a little over 30 percent in preferred species. A major problem is that much of the forest land is in small tracts in private ownerships which do not respond to normal inducements for improved harvesting and management methods.

The hardwood forest sites in the Eastern United States have the potential for producing high quality wood, but they must be managed more intensely. Improved processing techniques are required to enhance the quality and grade of solid wood products, such as structural lumber and furniture stock. The major difficulties involve drying and dimensional stability, machining, and energy efficient processing. Efficient harvesting is required for improved management, but the trees that must be removed are the smaller or lower valued species that presently may not pay their way out of the woods.

An additional problem is the large volumes of low value hardwoods occupying softwood sites--in the South, these often occur mixed with the pines. Regeneration of these areas requires the removal of the hardwood biomass after the pine is harvested.

Management of softwood forests requires thinning operations to speed the growth of pulpwood, pole, and sawtimber. Short-rotation intensive-culture plantations offer potential to increase biomass supply, but the physical and mechanical properties of this raw material must be determined in terms of end-use requirements.

Following harvesting of high-value trees, the material that remains is low in value due to size, form, species, or quality of wood. The greatest opportunity to manage these eastern forests is through whole tree removal and processing. Innovative research approaches are needed to convert the whole tree into products such as reconstituted panels, fuel, pulpwood, and specialties that will permit removals to be made on a economic basis.

The research approaches should also consider the international market opportunities for finished or value-added products. The hardwoods of the Eastern United States have great potential for supplying fiber and wood demands--particularly in Europe as wood from developing countries become more scarce and expensive. They could well balance overall import/export trade for wood products in the United States.

SOME GUIDELINES FOR LEADERSHIP

From the very beginning, the Forest Service has tried to maintain world leadership in all important areas of wood research. When FPL was established in Madison, it became a comprehensive laboratory and tried to maintain the same leadership goals in all areas. The concept of leadership continued with the establishment of the various stations.

Now the Forest Service is at a point where it needs to maintain its comprehensive coverage, but must yield on the leadership goals in some areas. This situation results from the fact that the budget base for research is diminishing at a time when the knowledge base in all disciplines is expanding rapidly. Hence, there is no real possibility for adhering to the previous leadership ideal. Furthermore, there are now many fine laboratories in foreign countries and in universities to share the burden of developing new information on wood. Improvements in world communication and transportation now bring these research centers into closer touch for effective exchange of information.

The administrative task will be to select areas for world leadership wisely. In general, the areas selected will be those of special importance in which the Forest Service is uniquely capable of making a significant contribution. The following discussion is intended to be helpful in identifying these areas and in improving the chances for a high level of success.

Although some success is likely to be achieved by any research effort, the goal of a world class research unit is to use its high intellectual resources to achieve major breakthroughs in high-risk, high-payoff objectives. Suitable

objectives can be deduced from a study of currently identifiable situations and technological problems, and it may be safe to say that there is no shortage of these. The administrative task, therefore, revolves around considerations of staff, organization, management skills, and facilities (including equipment). Of these, staff is all-important.

The staff of an area of research selected for world leadership ideally should cover both the science and the technology of the subject. Often, the science is represented by more than one professional discipline. It is important that at least one of these, preferably the dominant discipline, be represented by at least one scientist capable of working at the so-called cutting edge of the discipline. This scientist provides a sense of leadership, not necessarily formal, but certainly well respected and readily available for consultation. The primary function of such a scientist is to provide a reliable assessment of the latest fundamental knowledge when critical points are reached and alternative directions are being discussed.

In mission-oriented research, the mission is seldom to develop fundamental knowledge for its own sake. Rather, fundamental studies are almost always aimed at some useful technology. Hence, this end of the spectrum is just as important as the science end. Often, scientific discoveries lead to new technologies; more often, technology inspires scientific discoveries. Hence, both elements are necessary to improve the chances of achieving breakthroughs in a specified area of research.

Organization, the second factor in the administrative task, is the manner in which the research talent is deployed. Commonly, scientists are in one group and technologists in another; sometimes for better coordination, they are in the same group*. In either case, chances of success are greatly improved when a rare type of individual is present who serves as an integrator, one who is capable of seeing a useful connection between separate discoveries. This may be a scientist, a project leader, or an assistant director, but the special talent must be recognized and made functional.

A third factor is management skills--not all-purpose management skill--but rather skill in developing and sustaining the fragile innovative spirit of scientists. As a general observation, most research organizations do not distinguish adequately between ordinary management and research management. There is an implicit assumption that career research scientists cast in the role of managers arrive there with full knowledge of research management skills. Unfortunately, this is not true. Special training in research management has the potential of large payoffs in the conception and survival of ideas. With the focus on adequate accomplishments, there is often too little concern for great ideas missed or destroyed. Skill in research management includes the ability to develop the proper atmosphere for intellectual work and creative manipulation of ideas. Above all, the research manager must recognize that he is primarily in a support role and that the scientists are the key operators of the organization. The research manager must also recognize that creative talent abounds in everyone--almost as an act of nature--and that he, the manager, carries some serious responsibility for making the creative urge flourish or die.

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* The term "technologist" is used in the generic sense and includes engineers. It refers to occupational activities rather than training or specific classification.

It is particularly important that the manager encourage communication between scientists and technologists. Despite a natural rivalry between the two, a harmonious relationship is essential for optimum progress. When primadonnas exist, the manager must find ways of channeling the intellectual energies to maximize the yield of good ideas for the group as a whole.

Although the Forest Service classification system is not very precise in distinguishing between scientists and technologists, there is a difference that should be recognized by research managers. In general, a scientist uses science to create more science; a technologist uses science to create or to explain technology. They may overlap in the same individual, or the individual may be capable of switching roles. However, a scientist used consistently as a technologist will eventually lose command of his discipline, but will become a better technologist and a lesser scientist. Mission-oriented research systems commonly drive scientists to become technologists, thus always depleting the ranks of the former. This has the effect of enhancing the achievement of immediate goals, but at the expense of long-term viability of the program. Research managers should be aware of this situation and will need to find ways of counteracting the effect of the trend.

The fourth factor, facilities, requires little comment. Breakthroughs cannot be expected if the facilities are inadequate to achieve the stated research objectives. The rate of development in new equipment and sophisticated instruments for research places real obstacles in the path of those seeking to be world leaders. To stay in the forefront often requires up-grading of expensive equipment when improvements involve refinements in measurement of something to be observed, or new equipment is developed to measure something previously done laboriously, or not at all. A commitment to leadership should include a commitment to maintain currency in the tools needed for the job.

Application of these four guidelines for leadership to any situation at hand will be difficult. Since federal employment regulations limit the building of an ideal research staff, particularly in times of retrenchment, some gaps and aberrations are bound to appear. The absence of GS/GM-16 and 17 scientists is a case in point. In these less than optimum circumstances, it appears wisest to rely more heavily upon management skills to remove obstacles, reduce frustrations, placate egos, and generally to extract the maximum intellectual output from each scientist. As indicated previously, these skills can be enhanced by special training. Programs for this specific purpose should be provided for all project leaders and assistant directors at research stations.

In addition to the above guidelines, another route to leadership involves a more effective application of a material science approach to wood research. This would lead to a higher rate of accomplishment in areas where good opportunities exist for significant breakthrough. In simplest terms, materials science implies an integrated continuum from raw materials to properties of the finished product. The continuum includes composition, internal structure, and processing variables. Although the concept of materials science is not new to other engineering materials, it is new for materials of biological origin, such as wood. Hence, its effective application to wood research provides a possible and logical route to leadership.

The concept of materials science is so important that a brief elaboration at this point may be appropriate. More than half of all wood used today in the United States is first taken apart and then put back together again. These products include paper, fiberboard, particleboard, flakeboard, plywood, laminated veneer, and laminated lumber. The basic principles of materials science can be applied directly and in full to these materials and processes. The properties of these materials are more dependent on the processing variables than on the properties of the parent raw wood. A whole new science of wood materials must be developed which is based on concepts of small pieces of various sizes and shapes bonded together in various orientations. Much of the existing body of wood science will be applicable, but new theories will be needed to explain the factors affecting strength and durability of these materials. Furthermore, the knowledge needs to be organized to provide predictive value in a synthesis mode of wood research.

For forest products research, the key implication is that end-use requirements can now realistically dictate the properties of wood materials, particularly those used in engineering applications. Hence, design engineers will have a greater voice in specifying properties than ever before, and innovative research in wood structures should therefore be more closely coordinated with the research of materials scientists. In addition, research on biodegradation, fire resistance, and dimensional stability needs to be similarly coordinated to open exciting new horizons for wood materials.

While materials science principles apply well to reconstituted wood materials, they apply less well to solid wood products. This is because composition and structure are fixed by nature, and because processing does little to alter properties. However, this situation is changing rapidly. Because of developments in tree genetics, fertilization, hormonal treatments, and silviculture, short-rotation tree crops will soon be an important factor in the wood supply. This means that the composition and structure of the raw wood will be under greater control. Now, the relationship of composition, structure, and properties--the essence of materials science--takes on new meaning, and it calls for a closer link between forest products research and forest management.

The foregoing discussion of leadership and the potential of materials science was intended to reveal opportunities for maximizing the yield from the research investment. It is recognized that significant discoveries have been, and will continue to be made under any conditions where scientists are at work. This is true because scientists are by nature resourceful people and they are by nature motivated by a challenge. The main thrust of the administrative exercise, therefore, should be to encourage the scientists to seek the larger challenges, and to provide proper sustenance to increase their chances of success in terms of major breakthroughs.

APPENDIX A

Forest Products Utilization Research in the United States

Research on wood and wood products in the United States is conducted at many universities, at a number of wood industry laboratories, and at several federal laboratories. The purpose of these three wood research entities are distinctly different, but because of close coordination and cooperation they are mutually supportive. They each play an important role in accelerating the adoption of new technologies--the ultimate goal of all research.

University--There are 26 universities with graduate programs in wood science and technology, all of which carry on some research. A number of these are of significant size and have fairly diversified research capabilities. Several of these research programs have strong ties with colleges of engineering. The total expenditure for wood research by universities in 1980 was $7.5 million.[1/] This includes funds received from foundations and industry, in addition to state funds.

It is difficult to characterize university research in wood and wood products. Whereas in earlier times, university research could safely be described as mostly fundamental, it is now common to observe the entire spectrum on most campuses. Some universities try to relate all research effort to graduate student programs and thereby suffer certain restrictions in regard to outside funding.

Most universities, however, are willing to undertake virtually any type of research for which faculty capability and equipment exist. Occasionally, even the lack of these pose no problem if the sponsor is willing to cover the cost of self-education for the faculty member and purchase needed equipment. The significance of this new trend is that the universities may be able to help bridge the gap when developments in Federal laboratories require an entreprenurial apporach in transferring new technology to industry. This will become more important in the future as new policies for Federal research call for more emphasis on the fundamental end of the spectrum and less on the development end.

The Forest Service has established a good record of cooperative research with most universities having wood research programs. Approximately 8.5 percent of the total FPUR budget was expended for extramural research over the past 5 years, and the trend continued upward. The Forest Products Laboratory has a good working relationship with over 30 universities, and regularly supports research in a number of university departments and disciplines. Because of its proximity, the University of Wisconsin is prominent in FPL's extramural program. Each of the Station's utilization projects also have strong ties to several universities.

1/ Information provided by W.K. Murphy, CSRS, Washington, DC, personal communication, Aug. 11, 1982.

These extramural projects with universities are usually directly related to an ongoing Forest Service project and are seldom isolated ventures. Besides advancing an existing Forest Service goal, these extramural projects help to sustain the flow of superior students, and for some students it gives them a wood orientation early in their career.

Industry--The wood industry as a whole is traditionally near the bottom of the list of manufacturing entities in regard to expenditures for research. Recent data (Fig. 1) show that wood industry R&D amounted to about $170 million for 1980, exclusive of paper and allied products.(2) Although this expenditure is very low compared to all other industries, it is roughly six times the amount expended by universities and government combined.

The distribution of this R&D effort by industry indicates a rather limited range of benefits. Although statistics are somewhat limited, available information shows that of the 46,000 companies comprising the wood industry in 1958, only 56 had more than 1,000 employees, and of the 56, only 23 had R&D programs.3/ Assuming some change since then, it is still apparent that most of the industry operates without an R&D effort and is largely dependent on public agencies, such as universities and federal laboratories, for new information leading to innovation.

The 46,000 companies comprising the wood industry is also the largest of all manufacturing categories. Data from the National Science Foundation also indicates that, of the industries listed, the wood industry may be the only one that does not receive government funds for research.3/ These facts about the wood industry may have some implications for the evolution and present status of government support of forest products research, in addition to those previously expressed.

Some of the larger companies, particularly the pulp and paper mills and large integrated producers, carry on significant research programs aimed at improvement of their own products and processes, or to achieve proprietary positions on new developments. One of the primary sources of innovation in the wood industry is in the smaller companies that do not support a visible research program *per se*. Innovation in these small companies occurs when a problem or an opportunity is perceived and the solution then quickly becomes the common goal of management, production, and salespeople. Under these conditions, decisions are made easily and progress can be swift. Most industry research may be characterized as applied, short term, and highly developmental in nature. Typically, the results are not made public.

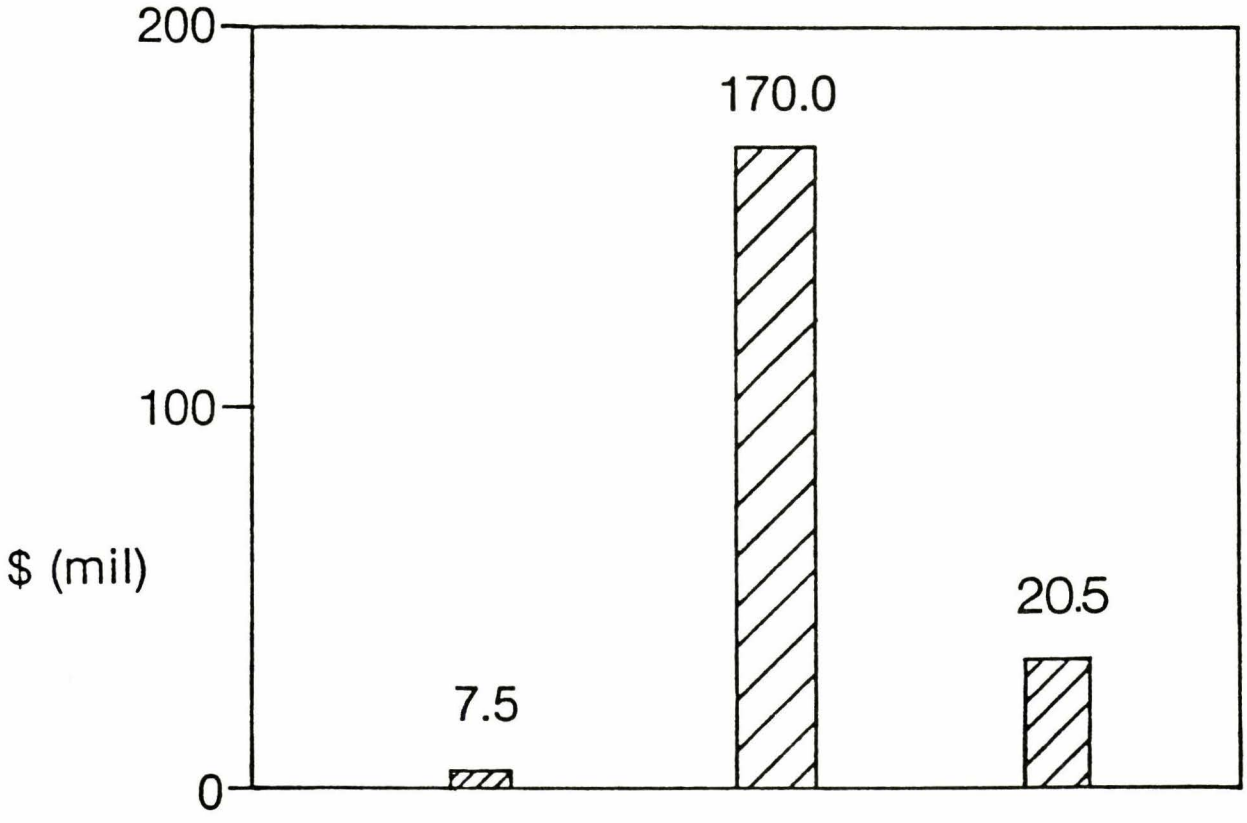
The more knowledgeable and alert a company is, the more active it is in seeking knowledge from university and government laboratories. Some enlightened companies sponsor research at universities and some make annual grants in recognition of the public service provided, but also in exchange for early awareness of significant developments, and first options in recruiting graduates.

2/ *Highlights*. Sciences Resources Studies, National Science Foundation, NSF 81-331, Dec. 31, 1981.

3/ Industrial R&D Funds, National Science Foundation, NSF 64-25, October 1964.

FIGURE 1

Wood Research Expenditures by Universities, Industry, and Federal Government, 1980



*Exclusive of paper industry

The wood industry is also the recipient of volumes of research results through the efforts of equipment and materials suppliers. These suppliers actively seek out new knowledge, provide an effective screening service, foster development, and transfer the technology to the wood industry as a profit-making sales effort. Suppliers also provide a considerable amount of troubleshooting service in all parts of the plant that impinges on the performance of their equipment or their material. This is particularly true of adhesive suppliers.

Although the wood industry would much rather gamble a dollar on product promotion than on research, there is reason to believe that the attitude of industry toward research is changing. This change is being fostered by a series of events beyond the control of the industry, but which threatens their survival. These events include pollution control laws, energy shortages, product liability exposure, and changes in and shortages of timber. In addition, virtually all segments of the wood industry have witnessed increased sophistication of equipment, including computerized process control.

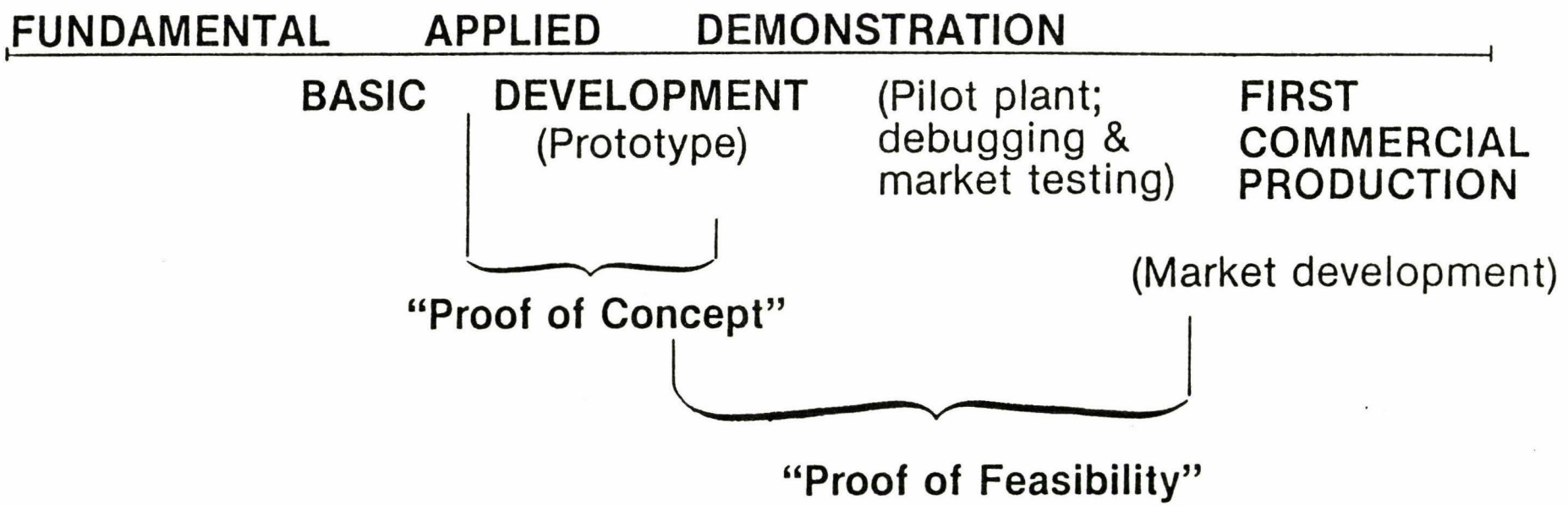
Although most companies depend upon suppliers to provide service, the cost of unscheduled downtime, suboptimum performance, and delays in production, can easily exceed the cost of in-house personnel trained to handle such problems. The net effect of this situation is that there has been a steady increase in the resident technical capability of the wood industry. These include forest products technologists, engineers, and graduates of technical schools. As this trend continues and as these people reach higher levels of authority, it can be expected that problems and opportunities will be more quickly recognized, analyzed, and acted upon. This action will more often be a contact with research somewhere, often leading to technology transfer in some form.

The Forest Service interpretation of this trend should be that the results of its research will be more quickly adopted, and not that its research will be needed less. However, the Forest Service should also recognize that industry generally is reluctant to adopt new technologies, particularly those just emerging from the laboratory and are yet untried both technically and economically. This is the stage where prototype development on new products or processes is involved and is therefore the stage when the Forest Service needs to appraise its role carefully. It is the stage when proof-of-concept for the scientist often merges with proof-of-feasibility for the industry. (See Fig. 2). As such, the active involvement of industry should be considered seriously. Cooperative ventures at this stage not only share the risk, but also facilitate the ultimate move toward commercialization. Current federal administrative policies and limited resources dictate that federal laboratories must pursue cooperative ventures when a proof-of-feasibility stage is reached in a development study.

It is important that a correct interpretation be made of the foregoing statements. While it is true that Forest Service research should emphasize programs at the fundamental end of the spectrum, it is not true that they should refrain from involvement at the other end. Any discoveries by Forest Service scientists recognized as having valuable practical applications should be pursued to the point where industry can take over at an appropriate level of risk. However, the key point is that industry must become tangible cooperators at some stage when prototype work is being planned and executed.

FIGURE 2

Research and Development Spectrum



Active involvement of industry will almost always be a matter of Forest Service initiative. Considering the natural reluctance of industry to adopt new technologies, chances for a successful approach on a cooperative venture are greatly improved when an atmosphere of confidence and trust exists between industry people and Forest Service scientists. This atmosphere is best developed when the scientists can demonstrate firsthand knowledge of plant conditions either through plant visits or through prior work experience.

A secondary route to improvement of the critical atmosphere is through attendance at technical meetings and participation in discussions involving industry people. Of course, when industry people visit scientists in their laboratories an advanced stage has already been reached in developing a good working atmosphere.

If technology transfer remains as a part of the performance standard for scientists, then increased travel funds should be budgeted to prepare the seedbed, so to speak, and thus improve the rate of success of the transfer stage.

Federal--Federal research in wood and wood products is concentrated in the Forest Service, and more particularly at the Forest Products Laboratory and several regional Forest and Range Experiment Stations. Other federal agencies, such as NBS, NASA, DOD, and CERL, carry on limited programs for their own purposes. Coordination with these agencies is usually quite casual, but cooperative projects have been undertaken, notably with DOD. HUD conducts research via contracts and grants, and occasionally these involve the Forest Products Laboratory and other Forest Service Stations.

Although coordination is less than formal, there is believed to be no serious duplication of effort among these agencies, at least at the study level. In more general terms, the research at other agencies involves either the structural properties of wood, or the use of wood in structures.

Other federal support of wood utilization research flows through the National Science Foundation and through the McIntyre-Stennis Act to universities. The Hatch Act, a longstanding federal program in agricultural research, also provides funds for wood utilization research where such programs are associated with Agricultural Experiment Stations.

Total Federal expenditures for wood research in 1980 was $20.5 million. This included $17.3 million FPUR/FS, $1.4 million USDA/CSRS, and $1.8 million other Federal agencies.

Roles and Responsibilities in Research

Questions often arise as to the role of industry, universities, and government in carying out various types of research. In industry, the research carried on is motivated by profits, and any new knowledge acquired is applied to something under development, or to solve a problem in a product or process. New knowledge is proprietary and ordinarily not shared with anyone. The type of research, whether fundamental or applied, must all lead to some fairly immediate practical objective of the company.

Universities, in contrast, have an obligation to carry on fundamental research. While all universities take the mandate of fundamental research seriously, some colleges within the universities, including Agriculture, Forestry, and Engineering, are equally serious about applied research, and even developmental research. Society expects breakthroughs in sciences to occur in universities because a scientist there can spend an entire lifetime in some limited area of inquiry with unlimited freedom to tap a wide variety of intellectual resources. In addition to breakthroughs in science, universities also produce major breakthroughs in so-called high technology areas.

University research is usually closely associated with graduate programs. There is some emphasis on the technique of research, as opposed to the results of research, particularly in master's programs. For this reason, research progress is tied into the university calendar and the results may not always be carried to a useful conclusion. Nevertheless, these programs remain as an excellent investment by both industry and government. Depending upon the style of the major professor, a steady stream of graduate students will produce coherent bits of knowledge to fit the jigsaw puzzle of a larger problem. Others may produce isolated bits of knowledge, lacking in coherence, but more likely to touch new lines of thought.

Several universities carry on programs of organized research in parallel with academic programs. In these institutions, projects are handled by professionals whose principal assignment is research and whose performance is guided by a director of research. In these cases, progress toward defined objectives may be more rapid than that of other institutions where academic schedules and programs take precedence over research.

The increase in sponsored research at universities has caused not only a more liberal view of its research objectives, but, unfortunately has also compromised its traditional role as an impartial, unbiased source of ideas and information. Although almost all universities zealously protect their right to publish their results without interference from sponsors, the source of funds automatically detracts from the claim of impartiality to some degree. This problem also afflicts government research agencies that require a similar image to properly serve the public. Funds for specific research received from outside the normal appropriation route carry the same potential stigma.

Government research contrasts with that of both industry and university in being definitely mission-oriented, but being strongly guided by the tenet of noninterference with the private sector. Accordingly, government research tends to be slanted away from development and toward the basic end of the spectrum, i.e., more like university than like industry research. However, the fundamental research in government laboratories is not the same as the free-spirit fundamental research of universities. In the case of government, fundamental research is almost always directed toward a mission, a fact that should not be construed as making it less fundamental. Rather, the results of mission-oriented fundamental research differ only in that they are more likely to be put to use in a shorter period of time.

Government research moves toward better understanding of factors involved in materials and processes, the formulation of new theories or revision of old ones, and the development of concepts for new technologies. Publication of the results of research in the public interest is mandated by law.

Aside from the above considerations, a further point regarding responsibility for certain types of research is worthy of reflection. When research is expressed as a spectrum or "integrated continuum," with fundamental research at one extreme and development at the other, the question normally focuses on who has the major responsibility for the fundamental portion. In contrast, the development portion of the spectrum is not usually discussed in terms of responsibility, but rather is assumed to be what industry does willingly and promptly for itself as a matter of self-interest. This view is not entirely correct. Most industries, aside from the "high technology" sector, are traditionaly slow to adopt new technology.

Considering the importance of development work for national productivity, national security, and the balance of trade, an assignment of responsibility for the end product of research would seem to be as appropriate as it is for fundamental research. Any lag in the development of new technologies is harmful for all three national concerns. From this viewpoint, it appears that the government has more responsibility than either of the other two for assuring progress of research through the development stage.

APPENDIX B

History of Forest Products Utilization Research in the Forest Service

Prior to 1910--Research in forest products in the United States was initiated in the early 1880s, under the U.S. Department of Interior, Division of Census, in the form of extensive timber tests conducted by C. S. Sargent at Harvard University. Later, under the Department of Agriculture, Division of Forestry, a timber physics program was established at Washington University in St. Louis, Mo. Other laboratories were established at a number of universities covering the mechanical properties of wood, wood preservation, wood drying, pulping, wood cehmistry, and naval stores. By 1905 cooperative work by the newly created Forest Service in the mechanical properties of wood was mostly centered at Purdue University, but other research arrangements were continued with other universities. An experimental pulp mill was being operated in Boston. In all, intermittent and widely scattered research activities in forest products were being conducted under cooperative arrangements at 15 locations.

These scattered activities, and their research results, were difficult to coordinate and to correlate. As a result, in 1908 the Forest Service requested funds from Congress for the construction of a central Forest Products Laboratory. This proposal represented a new idea in forest products research, the "team approach" to solving the problems of wood processors, fabricators, and users. However, this proposal was rejected by the Congress. In 1909 the Forest Service suggested to a limited number of universities that forest products research might be centralized at an educational institution which would provide an adequate building for this use. Several offers resulted and a proposal from the University of Wisconsin was accepted.

From 1910 Through World War I--Early in 1910 a building was completed on the campus of the University of Wisconsin and on June 4 of that year the world's first Forest Products Laoratory was formally opened. For the first time, problems in utilization were attacked under one roof by a team of trained specialists, including engineers, chemists, foresters, wood technologists, pathologists, and others. Since that time, the specialist team appproch to forest products research has been extended to most parts of the world. The 1910 Forest Products Laboratory was staffed with 45 people, including research workers largely gathered from the universities which had been cooperating with the Forest Service. The first few years of the Laboratory's life were spent mostly in organization, in laying a firm foundation for a permanent program, and in the continuation of research along lines followed previously at the universities.

By World War I the Laboratory was ready to take its place as an important national research institution. Major contributions to the military successes were made in the kiln drying of aircraft Sitka spruce; the fabrication, gluing, and finishing of aircraft propellers; and the design of containers for overseas shipment. These war-connected activities laid the groundwork for later industrial developments and progress in fields such as kiln drying, modern assembly gluing, glued laminated arches and structural members, molded plywood, and present-day packaging methods.

World War I Through World War II--The end of World War I found the Laboratory staff of 1910 expanded from 45 to 450. This staff was reduced quickly to about half, and continued to decline slowly for about 20 years.

The between-the-wars' years were fruitful ones, however. Partly as dividends of World War I research, contributions of this period included the discovery of the clorinated phenols for use in wood preservation, development of the stress-skin plywood house wall, floor, and roof panels, the invention of the semichemical pulping process, the formulation of design principles for glued laminated structural timbers, the development of engineering data needed for the use of metal timber connectors, basic research which resulted in the development of electric moisture meters, the stabilized woods "compreg," "impreg," and "staypak" were developed, and the complete carbohydrate fraction or wood, "holocellulose," was isolated.

In 1932 the Forest Products Laboratory moved into its present U.S.-owned building which provided greatly improved facilities, expanded working space, and better internal communications.

By the late 1930s, international tension indicated the probability of World War II and increased Congressional appropriations made possible further staff expansion. Some work on military research was possible prior to World War II, and at the time of Pearl Harbor the Laboratory was somewhat prepared. The Second World War saw the Forest Products Laboratory staff increased to a maximum of nearly 700, housed partly in outbuildings at the present site and partly in a building rented in downtown Madison. Some lines of research were operated on a three-shift basis.

World War II contributions of the Laboratory were highlighted by several major specialized research efforts and a large program in personnel training for military work. Metal scarcities required widespread wood substitution, and the development of special treatments and new wood-fabricating methods. Much of the research effort was spent on wood, and plywood, used in aircraft (for flight training, light cargo planes, and gliders). Problems of plywood strength determination, seasoning, gluing, species substitution, bending, preservative treatments, and finishing were solved. Another major research activity covered the selection, seasoning, and fabrication of ship timbers. Packaging research, training, and inspection were all major activities. In packaging, the Laboratory developed procedures for reducing military overseas shipping space requirements by one-third because of improved packing and container design. The Laboratory trained over 13,000 military and civilian inspectors, mostly in the fields of aircraft wood selection and processing.

World War II to Present--After World War II the Forest Products Laboratory staff was rapidly reduced to less than 400. The requirements of the U.S. military agencies for research information on wood continued after the war, but there was a period of increased demand for technical information during the Korean War.

As was the case following World War I, much of the World War II research was consolidated, completed, or continued at the Laboratory for later widespread industrial and military application. This was true especially

in the fields of fabrication, gluing, and molding of plywood; the production of glued laminated structural members, work on nonmagnetic minesweepers; and packaging.

The Laboratory research program has continued to accumulate basic information on strength properties, improve methods of wood pulping, develop new or better wood finishes and methods of preserving wood, develop methods for reconstituted wood products including adhesives, and increase our knowledge of wood as concerns growth structure-quality-property relationships.

During the first 30 years of its existence the Forest Products Laboratory became increasingly aware of the need for closer "grass roots" relations with other activities of the Forest Service, with industry, with changes in forestry conditions, and with the general public. In 1908, and for a few years thereafter, a specialist in forest products was assigned to Region 3. During the period of World War I through 1945, some improvement in this phase of operation was achieved by the establishment of "Offices of Forest Products" in the West (Regions 1, 5, and 6). Men assigned to these offices kept in close touch with the Laboratory, reflected the research needs of their Regions, and conducted limited local research and testing--more especially in mill-scale studies, service testing of treated railway ties and poles, and in air-drying studies.

A major step forward in this area was achieved in 1944 when the Congress appropriated funds for the establishment of the Forest Utilization Service units at the Southern and Northeastern Forest Experiment Stations. In 1945 these units were established at five additional Stations and, eventually, at eight of the nine Stations in operation. The primary functions of the Forest Utilization Service were:

a. To analyze the wood-using problems of their respective Regions and to determine the best approaches to problem solutions.

b. To present these problems to the Forest Products Laboratory or to other qualified agencies for research.

c. To improve forest utilization practices by bringing present technical knowledge and the results of further research to the industries, wood users, and timber growers of the respective territories.

These objectives were effectively achieved and contributed largely to the Forest Service research program in forest products. In some areas of research, such as log grade formulation, the Forest Utilization Service units made large contributions to research objectives.

In 1957 the name "Forest Utilization Service" was changed to the Division of Forest Utilization Research at all Forest Experiment Stations. These Divisions retained all of the functions of the Forest Utilization Service and had the additional responsibilities of planning, supervising, and coordinating all research at the Stations in the field of forest products. This role changed to the extent that each utilization project at the Stations is now conducting indepth research on specific regional utilization problems.

APPENDIX C

Examples of Important Accomplishments

A summary listing of the major accomplishments of the Forest Products Utilization Research is presented below to indicate the scope of research activities and to reveal the connection between research in the Forest Service and important developments in the wood industry and the economy.

1. Completed basic strength tests on more than 175 American woods, thus laying the technological groundwork for the utilization of wood for many structural purposes.

2. Developed the stress-skin plywood panel system for prefabricated houses. Probably up to 40 percent of all homes built use some degree of plywood panel systems.

3. Tested and developed fabrication techniques and engineering design methods for glued laminated construction, thus forming a new industry to supply elegant timbers for auditoriums, churches, gymnasiums, and other large structures.

4. Developed the basic patents and designs for modern lumber dry kilns to replace and improve older methods of seasoning in outdoor yards.

5. Pioneered in the art and science of kiln drying, including the development and publication of accelerated and safe drying schedules.

6. Pioneered in the development of electrical instruments now commonly used for quick determination of wood moisture content.

7. Developed the double diffusion treatment of wood with water-soluble preservatives which result in an insoluble toxic remaining in the wood. Successfully used in treating fence posts, this method had also been used in the treatment of wood cooling towers throughout the United States.

8. Established the relationships between chemical constituents of compounds and their toxicity to living organisms and in applying this information discovered pentachlorophenol, a clear oil-soluble water-repellent preservative for wood having numerous applications, including the dip treatment of window sash and other millwork.

9. Determined the relative paintability of American woods. Established, by groups, the paint-holding characteristics of wood; determined the wearing characteristics of common paint types; paint-priming techniques; optimum repainting shcedules; and other pratices involved in the effective use of paint on wood.

10. Developed a natural wood finish of high durability for use on redwood, cedar, cypress, and other species of siding as a substitute for the popular but nondurable clear finishes previously used. In addition, the FPL developed an improved stain formulation for long-term protection of exterior wood surfaces that is still widely used.

11. Developed "impreg" (a resin-impregnated laminated wood) and "compreg" (a resin-impregnated laminated and compressed wood) to meet the need for wood-base materials having resistance to moisture absorption and possessing low-swelling and low-shrinking properties. Impreg is now used in making models for automobile body dies with a saving of millions of dollars each year.

12. Invented the semichemical pulping process, a high-yielding method for pulping hardwoods. By 1957, 35 pulpmills were producing over 1.6 million tons of pulp by this process which permitted increased utilization of the hardwood species.

13. Established the engineering principles of box and crate construction, blocking, bracing, car loading, cushioning, waterproofing, and test and inspection procedures now widely used by industry, agriculture, and the military agencies.

14. Developed the basic system and procedures for establishing log grades. The hardwood log grades established are now standard for Forest Service use and have greatly facilitated estimates of forest productivity and lumber yields.

15. Discovered the basic relationships between tree growth and wood quality, and between wood structure and its properties; pioneered in the studies of subnormal and abnormal wood, its causes and detection. This has led to better silvicultural practices and better selection techniques in grading structural lumber.

16. Developed the cold soda pulping process which results in high-yield and low-cost pulps from certain hardwoods. This process has been in use for over 50 years by many companies.

17. Established the physical properties of the wood of southern pine species (longleaf, shortleaf, loblolly, and slash) and provided the means of achieving more effective use of this resource with improved performance. Developed an understanding of the relationship between density, strength, and elastic properties in statistically precise terms for the complete species range. These density data over the entire growth range are of great value to the forest managers and to the pulp and paper industry since pulp yields vary in direct proportion to density of the wood pulped.

18. Published the "Wood Handbook" which is the basic information source for engineers, architects, and builders selecting and using wood in structures. It contains information on physical, chemical, and mechanical properties of wood and how these properties are affected by variations in the wood itself. Design considerations are given to lumber, plywood, structural sandwich and laminated members, along with fasteners, gluing, fire resistance, finishing, preservation, and thermal insulation.

19. Developed a lightweight truss-framed house with an improved framing system directly applicable to residential or light-frame construction. It consists of special floor system, trussed rafters, and conventional wall studs all tied together with rigid joints into a unitized frame. Superior performance in both strength and stiffness have been demonstrated by full-scale structural tests. Savings of up to 30 percent in framing material are possible.

20. Completed an engineering analysis of heat loss, coupled with total cost effectiveness over the useful life of a home to demonstrate that there is an optimum insulation thickness for any climate. This optimum thickness results in least total cost of insulation and operation for life of the building and reduction in energy use. Estimated energy savings of more than 1,400 trillion Btu's per year are possible if applied to existing homes with insufficient insulation, and additional savings of 6,000 trillion Btu's are possible over a 10-year period by improved design of new construction.

21. Developed a "Best-Opening-Face" system (BOF) which unerringly determines the best sawing pattern for each and every log to facilitate the maximum possible yield. The average increase in yield is approximately 10 percent, depending on log size. The total lumber production of mills using the BOF system or its derivatives is approximately 6 billion board feet annually. An estimated $90 to $100 million are saved with this method. Within a 2-year period, BOF became a generic term for the use of computers in sawmill decisionmaking.

22. Developed a processing and drying system for producing usable aspen and yellow-poplar studs with reduced warp. Extensions of research to other hardwood species may significantly reduce the need for softwoods that have traditionally been used for structural members in light construction applications.

23. Developed a lumber dryer with a solar energy collector made of recycled aluminum beverage cans; cuts drying time in half with better quality lumber than conventional air drying. Also, a low-cost solar collector built into the ground supplies heat to a kiln. A novel design which lowers the cost of drying and consumption of fossil fuels.

24. The Forest Service Structural Flakeboard Program showed the technical and economic feasibility, from harvesting through marketing, of producing a structural grade sheathing board from hardwood and softwood residues. This opens a new, high-quality use for forest residues which can serve as a substitute for softwood plywood. Seventeen plants are now in various stages of implementation.

25. Demonstrated a potential for using micro-organisms to degrade lignin for: (1) the partial nonpolluting bleaching of kraft pulp, (2) pretreatment of wood to lower costs and energy to make groundwood pulp, and (3) decolorizing colored pulpmill liquid effluents.

APPENDIX D

Coordination of Utilization Research

Coordination of wood research efforts is critical since funding made available from the three major participants--universities, industries, and federal agencies--is limited. Internal to the Forest Service, a series of activities take place to assure that individual work units conduct research on the highest priority problems. These work units, 20 at the Forest Products Laboratory and 9 at the regional Forest and Range Experiment Stations, have 5-year work charters called Research Work Unit Descriptions (RWUDs) that state the research mission, problem selection, and expected accomplishments.

The RWUD is drafted with input from user groups within and outside of the Forest Service. It is reviewed carefully by the Director and Staff of the originating work unit (i.e., Forest Products Laboratory or Forest and Range Experiment Stations) to assure that it conforms to the goals of the organization. It is then reviewed by the Deputy Chief and by the staff of Forest Products and Engineering Research in the Washington Office for conformance to the short- and long-term goals of the Department of Agriculture and the Forest Service and to make sure that duplication of effort is avoided. When all differences in opinion are resolved, the RWUD is approved, and scientists then prepare study plans to carry out the work.

Coordination between work units is accomplished by several means. Study plan summaries and reports are exchanged for review and comment, and contact between scientists is maintained through technical conferences, and by phone and site visits. Every 4 years a Combined Program Review is conducted at each Station and the Forest Products Laboratory. Coordination of programs is one of the key issues at these reviews conducted by the Deputy Chiefs for Research and Administration. Another mechanism for coordination is the Technical Assistance Visit (TAV) which is conducted by one or more of the Washington Office research staffs. These visits address the finer details of the ongoing research and future program direction.

Additional coordination is accomplished at formal meetings held with universities and industry. In the past, the primary means of coordination came through meetings of organizations such as the Forest Products Research Society, workshops, seminars, and individual contacts. More recently, as a result of the Resource Planning Act, 1974, and Title XIV of the Food and Agriculture Act of 1977, a formalized process of research planning was undertaken.

This planning process was implemented by establishing four regional Forest Resource Planning Groups to develop separate but coordinated regional working conferences. The result was a priority listing of research needs. This activity was continued at a national conference where 51 major areas of research were identified as needing increased emphasis. Utilization research was included along with the other areas of forestry research.

This planning process provides a good basis for identifying important areas of research, but it has been found to be inadequate for indepth planning and coordination of programs involving utilization research with universities and industry. Part of the problem was that the regional planning groups had a regional focus and could not address fully those research programs unique to the Forest Products Laboratory, which has national responsibilities.

To overcome this problem, a Forest Products Utilization Research Subcommittee of the National Planning Group (NPG-2) for Research was formed in 1981 to specifically address the full scope of the utilization research program planning and coordination. Four regional university representatives and four Forest Service representatives headed by the Director of the Forest Products Laboratory and the Director, Forest Products Utilization Laboratory, Mississippi State University (Cochairman of the group), were charged with developing an improved process for planning utilization research programs. The focal point for the subcommittee activities is the Forest Products Utilization Research Conference (FPUR Conference) held annually each fall at the Forest Products Laboratory. The 1981 FPUR Conference featured the research programs at the universities and reports of working groups set up to identify future research needs in specific program areas. These reports became the working information for the subcommittee and it is serving the need to improve coordination with universities.

Coordination with industry follows a somewhat similar pattern and occurs primarily at the industry liaison meeting held annually at the Forest Products Laboratory. This includes the National Forest Products Association, Committee on Research and Evaluation (NFPA/CORE), and the American Paper Institute/Technical Association of the Pulp and Paper Industry (API/TAPPI) committees. In addition to the annual meeting, NFPA/CORE has established subcommittees to review utilization projects at the Stations. These subcommittee activities are then addressed at the annual meeting held in Madison, Wis. The latest effort to improve coordination involves formation of a new committee to represent the hardwood industry and it will function in harmony with NFPA/CORE.

As described above, considerable time and effort is spent in coordination of industry, federal, and university research programs. This effort is now working effectively and should not be diminished.

APPENDIX E

Current Research Programs at Stations by Project

For purposes of this report some elaboration of the programs at each Station may be helpful.

Intermountain Forest and Range Experiment Station (INT-3251). This group of four scientists located in Missoula, Montana, is working on ways of improving the technology for harvesting, preprocessing, and marketing of low-value timber from steep slopes. They are also working on the effects of timber harvesting as a tool for multipurpose land management.

North Central Forest Experiment Station (NC-1152). Three scientists located in Rhinelander, Wisconsin, are studying intensively cultured plantations from the standpoint of growth factors and the quantity and quality of wood and fiber.

(NC-3201). Four scientists located in Carbondale, Illinois, are addressing problems of recovering solid wood values from residue hardwood material. This includes development of new or improved processes for conversion and drying. Other research deals with improved machining methods for dimension parts.

Northeastern Forest Experiment Station (NE-3102). Four scientists located at Delaware, Ohio, are working on systems for predicting the yield of various products, including chips, from mature hardwood and softwood timber. Other studies deal with alternative stand manipulation techniques related to future products from young hardwood stands.

(NE-3201). Another group of four scientists located at Princeton, West Virginia, is studying methods of increasing the yield of solid lumber products from low-grade hardwoods. Techniques being developed include gang ripping, serpentine end matching, and a system of common parts.

Pacific Northwest Forest and Range Experiment Station (PNW-2107). A total of 4.3 SYs from a group of eight scientists in Portland, Oregon, is assigned to study methods of reducing logging residues and the environmental effects of such reduction. The residues are beinglconsidered as an energy source.

(PNW-3101). Another group of five scientists in Portland, Oregon, is studying the problems of utilizing dead softwood timber, including quality and yield studies.

Southeastern Forest Experiment Station (SE-3101). Four scientists are studying ways of characterizing whole trees in terms of volume and weight to improve utilization and are also collecting information on the geographic distribution of wood suitable for fuel.

(SE-3201). One scientist located in Asheville, North Carolina, is developing an integrated system for processing low-quality hardwood into high-value furniture cuttings.

(SE-3501). Five scientists located in Athens, Georgia, are developing a system to convert woods-run trees in mixed hardwood/softwood stands into substitutes for structural lumber and plywood with high utilization efficiency.

This group is also studying the service life of nails in treated wood foundations and developing adhesives to replace nails for this purpose.

Southern Forest Experiment Station (SO-3201). Five scientists located at Alexandria, Louisiana, are studying fundamental wood properties and new processing systems to improve the utilization of southern woods, including low-grade hardwoods. This includes harvesting systems, structural reconstituted wood products, and new adhesives for the latter.

APPENDIX F

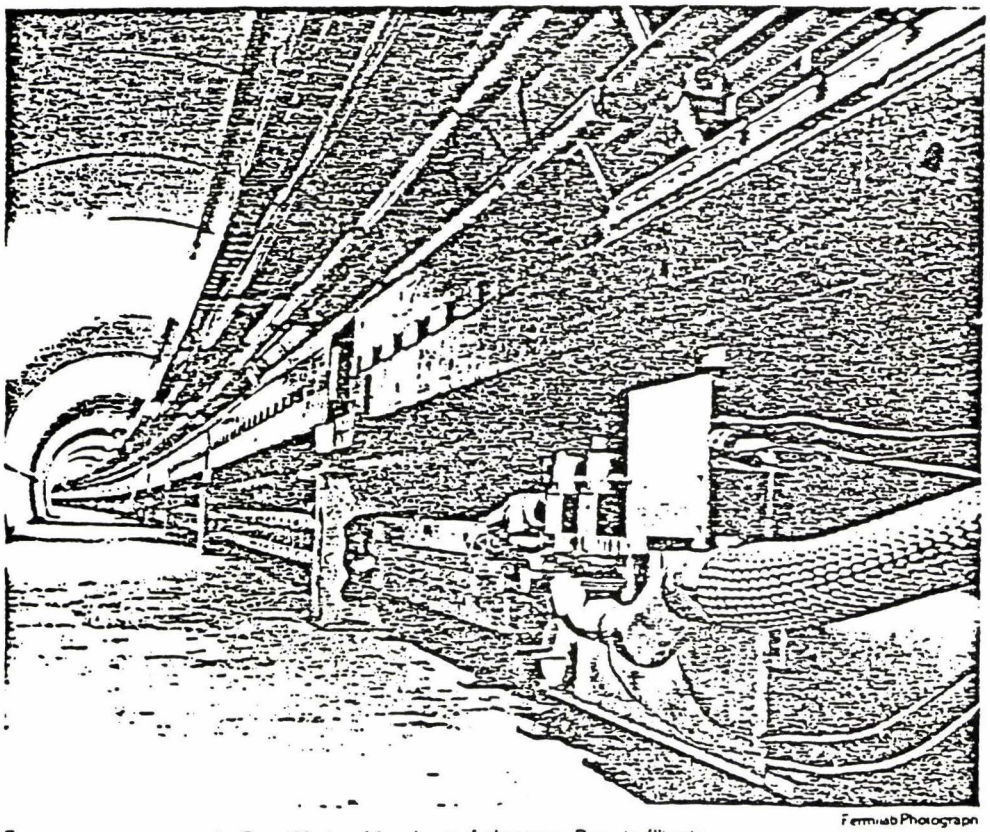
Introduction

The Federal Government owns more than 700 laboratories of various sizes engaged in what can be generally described as research, development, testing, and evaluation. Most are operated by Federal employees, but some of the largest facilities are operated by contractors. More than 70 percent of the laboratories have fewer than 50 professional staff members, and fewer than 20 percent have more than 100 professionals. Slightly more than one-third of the annual Federal R&D budget is allocated for the laboratories; a portion of those funds ends up in universities and industry for activities that support the laboratories' missions.

All the laboratories were originally established to meet specific needs related to the missions of their parent agencies. Their activities include agricultural research, consumer product testing, weapons development, energy research, biomedical research, and development of standard weights and measures, to mention only a few. Some, most notably those concerned with agriculture, were established in the 19th century, while others, particularly those involved in space technology, are of recent origin. Their accomplishments have been impressive, and they employ a significant fraction of the Nation's best trained and most qualified scientific and technical personnel. As a group they form a national resource of which the United States can be justly proud.

Trends and Developments

Over the past 10 years there has been an upward trend (in constant dollars) in Federal funding for R&D in the three major performing sectors: industry, Federal laboratories, and universities. The fraction



Fermilab Photograph

Energy saver magnets at the Fermi National Accelerator Laboratory, Batavia, Illinois.

Excerpt from "Annual Science and Technology Report to the Congress: 1981, Office of Science and Technology Policy in cooperation with the National Science Foundation. Superintendent of Documents, Washington, D.C. 20402: Stock No. 038-000-0504-9.

going to Federal laboratories has been relatively constant over that period. In general it may be said that industry is principally involved in development, the Federal laboratories in applied research, and universities in basic research. There are, however, many exceptions. The overlapping capabilities among the three performing sectors in many areas of endeavor make it increasingly difficult to identify capabilities truly unique to any one sector. In addition, all sectors need to maintain some level of activity in basic science and engineering to support the more applied aspects of their work.

Policy Issues

Although having overlapping capabilities is evidence of our national strength in science and technology, this overlap creates problems of choice in allocating Federal resources. The Federal laboratories were established originally to do work that could not be performed by, or was inappropriate for, the private sector. With the passage of time, however, many of the original objectives have been met, some of the missions are no longer relevant, and industry and the universities now have significantly greater research capabilities. The Federal laboratories have responded to changing environments in different ways, as have industry and the universities. Some laboratories have remained static, while others have ventured far afield from their original assignments. In such a dynamic situation, the Federal Government must strive to ensure that its resources are being allocated to the most relevant activities and to the most appropriate performing sectors.

Along with the challenge of effective allocation of Federal R&D funds, there also exists the challenge of improving cooperation among the performing sectors. The total national capability in science and technology must be harnessed efficiently if the United States is to continue its scientific and technological leadership. That means creating a synergistic relationship among industry, Federal laboratories, and universities, capitalizing on the strengths of each. It involves rethinking the traditional interactions and overcoming a number of institutional barriers.

Another issue pertaining to Federal laboratories is the vitality of the laboratories and their ability to do high-quality work, both now and in the future. Although the laboratories operate in different environments, each agency should be able to measure the productivity of its laboratories against an accepted set of criteria. A realistic assessment of the laboratories is necessary in determining the extent of their current and expected contribution to the Nation's science and technology endeavors. The Nation needs to be assured that funds allocated to Federal laboratories are indeed yielding a significant return.

These and similar issues have not been generally addressed for at least 20 years, and now is an appropriate time to explore them. Finding ways to make our R&D institutions more productive and better able to work together in maintaining U.S. scientific and technological leadership is a national challenge.